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# Characteristics of Lakes in the Eastern United States. Volume 1. Population Descriptions and Physico-Chemical Relationships

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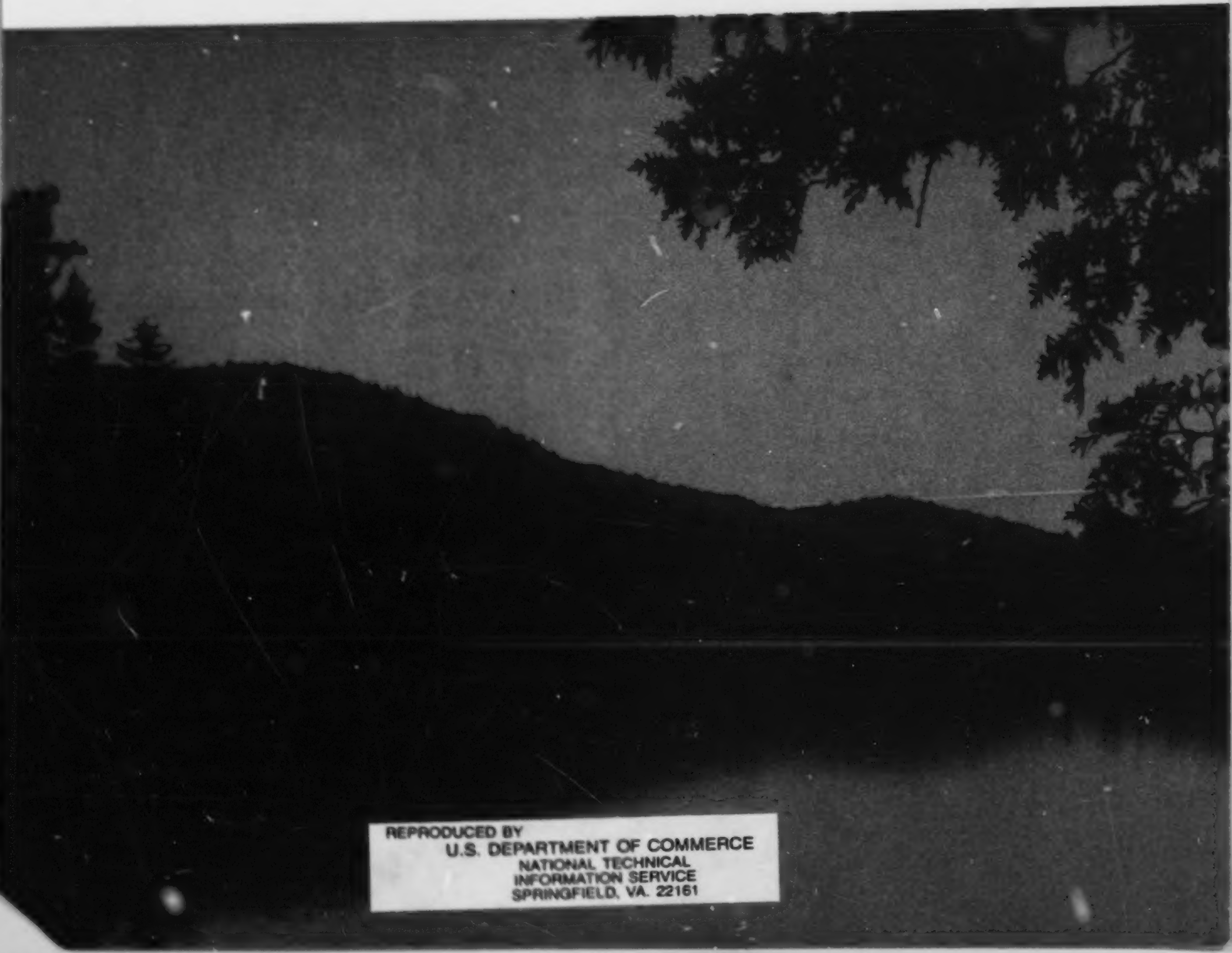
# Characteristics of Lakes in the Eastern United States

## Volume I. Population Descriptions and Physico-Chemical Relationships



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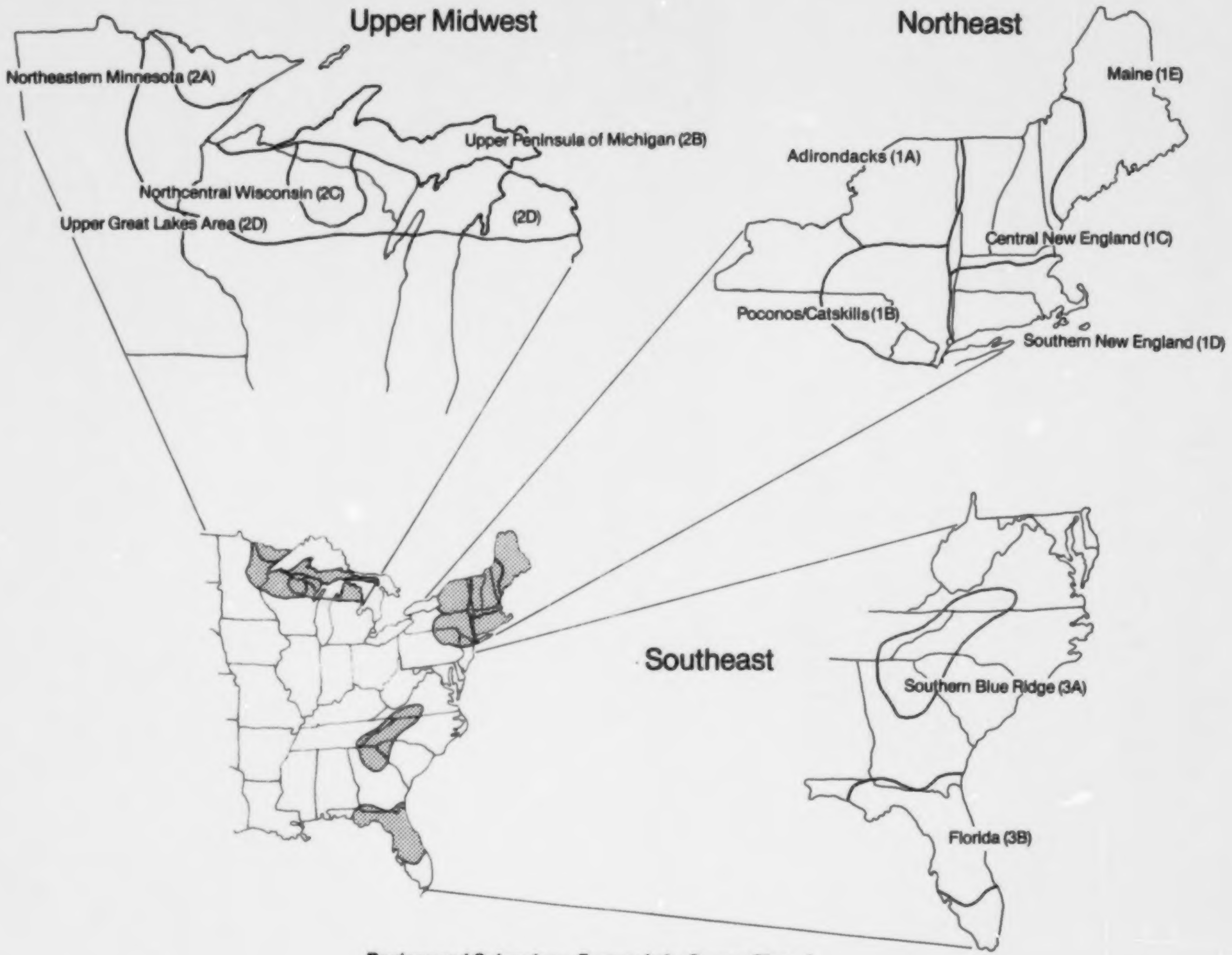
Upper Midwest
Northeastern Minnesota (2A)
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Northcentral Wisconsin (2C)
Upper Great Lakes Area (2D)
(2D)
Northeast
Maine (1E)
Adirondacks (1A)
Central New England (1C)
Poconos/Catskills (1B)
Southern New England (1D)
Southeast
Southern Blue Ridge (3A)
Florida (3B)

Regions and Subregions, Eastern Lake Survey-Phase I

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16. ABSTRACT

A water sample was collected from each of 1612 lakes. This subset of lakes was selected from within three regions of the eastern U.S. (the Northeast, Upper Midwest and Southeast) expected to exhibit low buffering capacity. Each region was divided in subregions. Subregions were further stratified by alkalinity map class.

A suite of chemical variables and physical attributes thought to influence or be influenced by surface water acidification was measured for each lake. The results of these measurements and data analyses are described. They comprise the Eastern Lake Survey - Phase I data base.

in the report

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## Volume I. Population Descriptions and Physico-Chemical Relationships

A Contribution to the
National Acid Precipitation Assessment Program

U.S. Environmental Protection Agency
Office of Research and Development, Washington, DC 20460
Environmental Research Laboratory, Corvallis, Oregon 97333
Environmental Monitoring Systems Laboratory, Las Vegas, Nevada 89109

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Inquiries regarding the availability of the Eastern Lake Survey-Phase I data base should be directed, in writing, to: Chief, Air Branch, USEPA Environmental Research Laboratory, 200 S.W. 35th Street, Corvallis, Oregon 97333.

## *Preface*

As part of the National Acid Precipitation Assessment Program, a Federal Interagency Task Force mandated by Congress in 1980, the United States Environmental Protection Agency (EPA) initiated the National Surface Water Survey (NSWS). The purposes of the NSWS are to assess the present chemistry of surface waters, quantify the temporal variability and key biological resources associated with these surface waters and initiate long-term monitoring in characteristic systems. The NSWS is a three-phase study focusing on regions of the U.S. that are potentially susceptible to change as a result of acidic deposition.

The NSWS is one of the several major projects in the Acid Deposition Aquatic Effects Research Program. This program, one of many research programs addressing acidic deposition, is administered in the Acid Deposition and Atmospheric Research Division: Office of Acid Deposition, Environmental Monitoring and Quality Assurance in the EPA Office of Research and Development.

The Aquatic Effects Research Program addresses four primary policy-related questions:

1. How extensive is the damage to aquatic resources as a result of current levels of acidic deposition?
2. What is the anticipated extent and rate of change to these resources in the future?
3. What levels of damage to sensitive surface waters are associated with various rates of acidic deposition?
4. What is the rate of change or recovery of affected systems, given decreases in acidic deposition rates?

Four major research projects within the Aquatic Effects Research Program specifically address these policy questions within a regionalized framework. These projects and their goals are:

(1) *National Surface Water Survey (NSWS):* to determine the present chemistry, characterize the temporal variability in chemistry, and determine the key biological resources of lakes and streams in potentially sensitive regions of the U.S.;
(2) *Direct/Delayed Response Project:* to predict future changes in these resources at present levels of acidic deposition, giving consideration to both the terrestrial and aquatic variables that influence these changes;
(3) *Watershed Manipulation Project:* to verify that predictions of future change are reasonably sound by manipulating watershed catchments or system components; and
(4) *Long-Term Monitoring Project:* to test the validity of predicted future changes through long-term monitoring of regionally-characteristic lake and stream systems.

The NSWS, including surveys of both lakes and streams, addresses the first goal of the Aquatic Effects Research Program. The Eastern Lake Survey-Phase I (ELS-I) was designed to statistically describe present surface water chemistry on a regional scale.

To further the current understanding of the effects of acidic deposition on aquatic resources requires that the present chemical status of surface waters be understood on large geographical scales. As individuals within the program and others in the scientific community continue to analyze the ELS-I data, we anticipate important scientific contributions to the understanding of regional lake chemistry and its relationship to atmospheric deposition. Causality cannot be determined from the results of ELS-I alone. Determining the relationships between acidic deposition and lake chemistry are the goals of future projects within the Aquatic Effects Research Program.

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## *Executive Summary*

The Eastern Lake Survey-Phase I (ELS-I) was conducted in the fall of 1984 as a part of the U.S. Environmental Protection Agency's (EPA's) National Surface Water Survey (NSWS). The NSWS is a contribution to the National Acid Precipitation Assessment Program, which is charged by the U.S. Congress to provide policy makers with sound technical information regarding the effects of acidic deposition.

The ELS-I had three primary objectives:

1. Determine the percentage (by number and area) and location of lakes that are acidic in potentially sensitive regions of the eastern U.S.
2. Determine the percentage (by number and area) and location of lakes that have low acid neutralizing capacity in potentially sensitive regions of the eastern U.S.
3. Determine the chemical characteristics of lake populations in potentially sensitive regions of the eastern U.S. and provide the data base for selecting lakes for further study.

To accomplish these objectives, a water sample was collected from each of 1612 lakes. This subset of lakes was selected from within three regions of the eastern U.S. (the Northeast, Upper Midwest, and Southeast) expected to exhibit low buffering capacity. Each region was divided into subregions, shown below:

| Region 1: Northeast | Region 2: Upper Midwest | Region 3: Southeast |
|---|---|---|
| 1A: Adirondacks | 2A: Northeastern Minnesota | 3A: Southern Blue Ridge |
| 1B: Poconos/Catskills | 2B: Upper Peninsula of Michigan | 3B: Florida |
| 1C: Central New England | 2C: Northcentral Wisconsin | |
| 1D: Southern New England | 2D: Upper Great Lakes Area | |
| 1E: Maine | | |

Each subregion was further stratified by alkalinity map class, which differentiated among areas within each subregion based on the surface water alkalinity range expected to dominate in different areas within these subregions.

A suite of chemical variables and physical attributes thought to influence or be influenced by surface water acidification was measured for each lake. The results of these measurements form the ELS-I data base.

The ELS-I design, in which lakes were selected by a systematic random process from the population of lakes in the regions investigated, permits the use of ELS-I data base to estimate the chemical status of lakes within a specific region or subregion. Additionally, the data base can be used to investigate correlative relationships among chemical variables on a regional basis.

The report which follows, *Characteristics of Lakes in the Eastern United States*, consists of three volumes. Volume I, *Population Descriptions and Physico-*

*Chemical Relationships*, provides details about ELS-I design and its implementation, presents data collected in the ELS-I, discusses results obtained and draws conclusions about these results. Volumes II and III contain descriptive statistics for each lake sampled and a data compendium of site characteristics and chemical variables.

This report is not intended to be interpretive. Rather, its purpose is to describe the results and to make the ELS-I data available to researchers and policy makers as more in-depth analyses and interpretive efforts are being undertaken. Analyses will be performed in subsequent phases of the EPA Aquatic Effects Research Program and by independent researchers.

The use and interpretation of any data set are restricted by the design, the quality of the data obtained and the sampling protocols, which are presented in detail in Sections 2, 3, and 4. These aspects of the Survey should be well understood before drawing conclusions both within and beyond the scope of the original objectives. For example, these data alone may not be sufficient to determine causality. However, Survey data, coupled with data from ongoing and future projects, are expected to significantly advance our understanding of the relationship between acidic deposition and lake water chemistry.

## Selected Results

The first two summary observations presented below address the first two ELS-I objectives. The remaining summary observations address the third objective of the Survey. These observations lead to hypotheses that can be tested in subsequent phases of the National Surface Water Survey and/or the Aquatic Effects Research Program.

It should be noted that the numbers and percentages of lakes cited here are population estimates.

### *Extent and Location of Acidic and Low pH Lakes*

The subregions in the eastern U.S. that contain the largest proportion of acidic (ANC $\leq 0$ $\mu$eq $L^{-1}$) and low pH ($\leq 5.0$) lakes are the Adirondaks (1A), the Upper Peninsula of Michigan (2B), and Florida (3B).

Acidic Lakes

- Within the Northeast (Region 1), the Adirondacks (1A) had the largest estimated number (138) and percentage (11%) of lakes with ANC $\leq 0$ $\mu$eq $L^{-1}$, followed by Southern New England (1D; 5%), and the Poconos/Catskills (1B; 5%). Maine (1E) had the lowest percentage of acidic lakes (<1%). Most acidic lakes in the Adirondacks occurred in the western portion of the subregion.
- In the Upper Midwest (Region 2), 10 percent of the lakes in the Upper Peninsula of Michigan (2B) had ANC $\leq 0$ $\mu$eq $L^{-1}$, and three percent in Northcentral Wisconsin (2C) were acidic. In Northeastern Minnesota (2A) and the Upper Great Lakes Area (2D) no acidic lakes were sampled.
- In the Southeast (Region 3), no acidic lakes were sampled in the Southern Blue Ridge (3A). In contrast, an estimated 22 percent of the lakes in Florida (3B) had an ANC $\leq 0$ $\mu$eq $L^{-1}$.
- Acidic lakes in the Northeast had higher concentrations of sulfate, calcium, and extractable aluminum than did acidic lakes in the Upper Midwest and Southeast.

Low pH Lakes

The estimated number of lakes and lake area with low pH (pH $\leq 5.0$) also varied substantially among and within regions.

- Within the Northeast, the Adirondacks (1A) had the largest estimated number (128) and percentage (10%) of lakes with pH $\leq$5.0. Subregion 1D (Southern New England) contained the second highest estimated number (66) and percentage (5%) and the largest area (2295 ha, 6%) of low pH lakes. Maine (1E) had the fewest lakes (8, <1%) and the least lake area (95 ha) with pH $\leq$5.0.

- In the Upper Midwest, no lakes with pH $\leq$5.0 were observed in Northeastern Minnesota (2A) or the Upper Great Lakes Area (2D). The Upper Peninsula of Michigan (2B) was estimated to contain 99 lakes with pH $\leq$5.0, representing nearly the same proportion as in the Adirondacks (9% and 10%, respectively).

- In the Southeast, no lakes with pH $\leq$5.0 were sampled in the Southern Blue Ridge (3A). Florida (3B) had the highest estimated number and percentage of lakes (259, 12%) and the largest estimated lake area with pH $\leq$5.0.

### *Extent and Location of Low ANC Lakes*

As observed with the estimates of low pH lakes, the estimated number of lakes with low ANC varied among and within regions.

- Within the Northeast, the Adirondacks (1A) contained the highest percentages of lakes with ANC $\leq$50 $\mu$eq $L^{-1}$ and $\leq$200 $\mu$eq $L^{-1}$ (35% and 70%, respectively). Central New England (1C) and Maine (1E) contained the next highest percentages of lakes among all ELS-I subregions with ANC $\leq$200 $\mu$eq $L^{-1}$ (68% and 67%, respectively).

- Northcentral Wisconsin (2C) contained the highest percentage (41%) of lakes with ANC $\leq$50 $\mu$eq $L^{-1}$ among all subregions. Northeastern Minnesota (2A) and Northcentral Wisconsin contained the highest percentage of lakes in the Upper Midwest with ANC $\leq$200 $\mu$eq $L^{-1}$ (57%). Although the Upper Great Lakes Area (2D) contained the lowest percentages in the Upper Midwest of lakes with ANC $\leq$200 $\mu$eq $L^{-1}$, it contained the largest number of lakes among all ELS-I subregions in this category (1411).

- The Southern Blue Ridge (3A) contained the lowest percentage (1%) and number (4) of lakes in the ELS-I with ANC $\leq$50 $\mu$eq $L^{-1}$ and the lowest number of lakes with ANC $\leq$200 $\mu$eq $L^{-1}$ among all subregions. Florida (3B) contained the highest number of lakes among all ELS-I subregions with ANC $\leq$50 $\mu$eq $L^{-1}$, and the second highest number of lakes with ANC $\leq$200 $\mu$eq $L^{-1}$.

### *Chemical Characterization*

#### Sulfate

Sulfate concentrations in lakes were greatest in Florida and the southern portions of the Northeast. No linear relationship between lakewater sulfate and pH or ANC was evident in any region. High concentrations of sulfate were found at low and high pH values.

- Sulfate concentrations were relatively high in the Northeast Region (median concentration (M) = 115.4 $\mu$eq $L^{-1}$). Within the Northeast, sulfate concentrations were highest in the Poconos/Catskills (1B; M = 159.3 $\mu$eq $L^{-1}$) and Southern New England (1D; M= 141.1 $\mu$eq $L^{-1}$). The lowest sulfate values were observed in Maine (1E; M = 74.6 $\mu$eq $L^{-1}$).

- The median sulfate concentration in the Upper Midwest Region was half that of the Northeast. Median sulfate concentrations also varied among subregions within the Upper Midwest, ranging from 50.1 $\mu$eq $L^{-1}$ in the Upper Great Lakes Area (2D) to 77.7 $\mu$eq $L^{-1}$ in the Upper Peninsula of Michigan (2B).

- In the Southeast, the Southern Blue Ridge Subregion (3A) contained few lakes with high sulfate (22 or 8% with $SO_4^{-2}$ ≥150 μeq $L^{-1}$). This subregion also had the lowest median sulfate concentration, 31.8 μeq $L^{-1}$. Floride (3B) contained the largest number of lakes with high sulfate concentrations (846 or 40% with $SO_4^{-2}$ ≥150 μeq $L^{-1}$). Subregion 3B also had the most variable sulfate concentrations of any subregion.

### Calcium

Calcium concentrations were lowest in the Upper Midwest and Florida lakes.

- Within the Northeast Region, Southern New England (1D) had the highest percentage and number of lakes with calcium concentrations ≤50 μeq $L^{-1}$ (10%; 133). The Adirondacks (1A) contained the second highest percentage and number (8%; 108) of low calcium lakes (≤50 μeq $L^{-1}$).

- Northcentral Wisconsin (1C) contained the highest percentage (22%) and second highest number (34) of low calcium lakes among all ELS-I subregions. The Upper Peninsula of Michigan (2B) contained the second highest percentage (16%) of low calcium lakes and the Upper Great Lakes Subregion (2D) contained the second highest number (256) of low calcium lakes in the Upper Midwest.

- In the Southeast, 12 percent of the lakes in the Southern Blue Ridge (3A) had low concentrations of calcium, whereas in Florida (3B), 19 percent of the lakes were in this group. Florida contained the highest number (402) of low calcium lakes among all subregions.

### Extractable Aluminum

Extractable aluminum concentrations were higher in lakes with lower pH values, and higher in the Northeast than in other regions.

- The largest estimated number of clearwater lakes (true color ≤30 PCU) having extractable aluminum concentrations ≥150 μg $L^{-1}$ occurred in the Adirondacks (1A; 82 lakes or 10%). Few lakes in the Poconos/Catskills (1B; 3 lakes or <1%) and Southern New England (1D; 7 lakes or 1%) had extractable aluminum ≥150 μg $L^{-1}$. No clearwater lakes sampled in Maine (1E) had extractable aluminum concentrations ≥50 μg $L^{-1}$.

- Extractable aluminum concentrations in clearwater lakes were lower in the Upper Midwest (80th percentile = 8.5 μg $L^{-1}$) than in the Northeast (80th percentile = 11.6 μg $L^{-1}$). Extractable aluminum was lowest in clearwater lakes in Northeastern Minnesota (2A; 80th percentile = 3.0 μg $L^{-1}$), and highest in clearwater lakes in the Upper Penninsula of Michigan (2B; 80th percentile = 11.9 μg $L^{-1}$).

- Extractable aluminum concentrations in clearwater lakes were low in the Southern Blue Ridge (3A; 80th percentile = 2.5 μg $L^{-1}$). In Florida (3B), clearwater acidic lakes had lower extractable aluminum concentrations (80th percentile = 18.6 μg $L^{-1}$) than did clearwater lakes in the Adirondack Subregion (1A; 80th percentile = 29.4 μg $L^{-1}$).

- In each region extractable aluminum concentrations were higher at lower pH values. The Northeast had the greatest increase in extractable aluminum with decreasing pH and Florida the least increase at low pH values.

### Dissolved Organic Carbon

Dissolved organic carbon (DOC) concentrations did not correlate with the distribution of acidic or low ANC lakes.

- In the Northeast, as in other regions, 80 percent of acidic lakes contained concentrations of DOC $<5$ mg $L^{-1}$. A positive relationship existed between pH and DOC. Those lakes with highest DOC concentrations were drainage lakes with short hydraulic residence times and high ANC.

- In the Upper Midwest, most acidic lakes, especially those in the Upper Peninsula of Michigan (2B) and Northcentral Wisconsin (2C), were clearwater, low DOC, seepage lakes. Lakes in Northeastern Minnesota (2A) had the highest concentrations of DOC in the Upper Midwest and no acidic lakes were sampled in this subregion.

- In the Southeast, only the lakes within the Okefenokee Swamp exhibited a strong association between low pH and DOC. No apparent relationship between pH and DOC was evident in Florida (3B) lakes.

### Major Cations and Anions

The anions were most useful in characterizing differences in the relative importance of major ions among regions and subregions.

- In the Northeast, sulfate was the predominant anion at the 20th percentile in three of the subregions (Adirondacks; 1A; Poconos/Catskills, 1B; and Central New England, 1C). Sulfate was also the dominant anion at the median value in the Adirondacks.

- In Maine (1E), bicarbonate ion concentrations exceeded sulfate at both the 20th percentile and the median.

- Chloride was the dominant anion in Southern New England (1D) at both the 20th percentile and median values estimated for the population.

- Bicarbonate was the dominant anion at the 20th percentile and median values in the Upper Midwest, with the exception of the Upper Peninsula of Michigan (2B) and Northcentral Wisconsin (2C), where sulfate was dominant at the 20th percentile.

- The ionic composition of lakes in Florida (3B) was similar to that of lakes in Southern New England (1D) in that sodium was the dominant cation and chloride the dominant anion at the 20th percentile. Total ionic concentration of many Florida lakes was high.

- Organic anions, as indicated by anion deficit, were not the dominant anions in any subregion at either the 20th or 50th percentiles. Concentrations of organic anions were lowest in the Northeast.

### *Future Studies*

Examination of the results of the ELS-I Survey presented in this report are largely descriptive but lead one to forumulate hypotheses that can be tested with this data base, singularly or combined with other data. The statistical design of the Survey makes it possible to test hypotheses related to acidification using regional data and relate the results to defined, regional lake populations. Five statements follow which are the results of the ELS-I Survey. Beneath each statement is a related question that should be addressed in the future:

- Sulfate concentrations in lakes across the Northeast and the Upper Midwest show an apparently strong relationship with the general patterns of sulfate deposition as measured by the National Trends Network.
  *What is the nature of the relationship between lake chemistry and atmospheric depositon of sulfate?*

- **The majority of acidic lakes in all three regions contained relatively low concentrations of organic acids.**
  ***How important are the contributions of organic acids in explaining the occurrence of acidic lakes?***

- **Some portions of the coastal areas of the Northeast contained moderate numbers of acidic lakes.**
  ***To what degree can the acidity of these coastal lakes be attributed to a neutral salt effect from sea spray deposition?***

- **The estimated hydraulic residence times for clearwater lakes were approximately 3 times greater than for darkwater lakes. Residence time was inversely related to DOC.**
  ***Does an apparent difference in hydrology between clearwater, acidic lakes and darkwater, higher ANC lakes indicate that acidic lakes generally are not derived from darkwater lakes?***

- **Florida (3B) contained the largest proportion of acidic lakes and the chemistry of many Florida lakes differed considerably in many respects from lakes in the Northeast, Upper Midwest and Southern Blue Ridge (3A).**
  ***To what degree are the acidic lakes in Florida affected by acidic deposition, and are other factors important in explaining the occurence of acidic lakes in Florida?***

# Section 1
# Introduction

The relationship between acidic deposition and the acidification of surface waters has become an important environmental issue in the United States and other nations. To assess the impact of acidic deposition on aquatic resources, many individual studies and analyses of historical data have been performed. The question of whether the pH and alkalinity or acid neutralizing capacity (ANC) of surface waters have been affected by acidic inputs of anthropogenic origin has been extensively reviewed, analyzed and debated (Drablos and Tollan 1980; NAS 1981; NRCC 1981; U.S./Canada 1983). Evidence from site-specific studies in the United States has been published that is consistent with the hypothesis that reductions in the pH and ANC of surface waters have occurred over time. In the analyses of chemical trends in lakes of the Adirondack Region of New York and in New England several authors have concluded that pH or alkalinity, or both, has declined historically from approximately the 1930's to the 1970's (Schofield 1976; Davis et al. 1978a; Pfeiffer and Festa 1980; Norton et al. 1981; Haines and Akielaszek 1983).

Despite these attempts to quantify changes in aquatic chemistry, the degree to which surface waters in the United States are threatened or have been affected by acidic deposition remains unknown. Uncertainty in extrapolating the results of specific studies to a regional or national scale continues, largely due to: the unknown degree to which individual study sites represent larger regional populations, unknown bias in lake selection, absence of measurements of chemical variables that are critical in assessing chemical or biological effects, difficulty in comparing data collected by different and sometimes unknown methods, and inconsistent documentation of quality assurance protocols.

Alkalinity and ANC have been used as indices of surface water sensitivity to acidic deposition (Altshuller and McBean 1980; Altshuller and Linthurst 1984). The actual sensitivity of a lake or stream to acidification, however, depends on the ANC generated both within the lake and its watershed. Hence, because many physical, chemical and biological factors, both aquatic and terrestrial, collectively determine the biotic composition and chemical environment within lakes, the response of an aquatic ecosystem to acidic depostion is a composite of many factors. Single-factor indices of potential sensitivity are, therefore, limited as indicators of response to acidic inputs.

Recognizing the limitations associated with available data and the complexity of predicting surface water response to acidic deposition, the U.S. Environmental Protection Agency initiated the National Surface Water Survey (NSWS) in 1983. The NSWS, which includes both lakes and streams, has three primary goals and three distinct phases: 1) quantify the present chemical status of surface waters in the U.S. (Phase I), 2) assess the temporal and spatial variability in aquatic chemistry and define the key biological resources associated with surface waters (Phase II), and 3) identify temporal trends in surface water chemistry and biology (Phase III). Each subsequent phase builds on the results of the previous one, ultimately identifying those lake or stream populations upon which to base a regionally characteristic, statistically sound long-term monitoring project designed to study long-term trends in chemistry and biological resources.

Phase I of the lake survey has two components, the Eastern Lake Survey (ELS-I) conducted in the fall of 1984 and the Western Lake Survey conducted in the fall of 1985. The results of the Western Lake Survey will be published in a report scheduled to be completed in late 1986. Phase II of the Eastern Lake Survey began in the spring of 1986. The existing EPA lake sites for long-term monitoring are currently being evaluated in light of the ELS-I data base for possible inclusion in the future Eastern Lake Survey (Phase III) Long-Term Monitoring Project.

The ELS-I was designed to provide the information needed to assess the chemical status of lakes in areas of the eastern U.S. containing the majority of low alkalinity systems. Lakes were selected statistically from the population of lakes within the northeastern, southeastern and upper midwestern regions of the U.S. Variables thought to influence or be influenced by surface water acidification were measured using standardized methods. The ELS-I data base may be used to investigate correlative relationships among chemical variables on a regional basis and to estimate the chemical status of lakes within a specific region.

The primary objectives of the ELS-I were to:

(1) determine the percentage (by number and area) and location of lakes that are acidic in potentially sensitive regions of the eastern U.S.;

(2) determine the percentage (by number and area) and location of lakes that have low ANC in potentially sensitive regions of the eastern U.S.; and

(3) determine the chemical characteristics of lake populations in potentially sensitive regions of the eastern U.S. and provide the data base for selecting lakes for future studies.

In addition to the primary objectives that guided the approach, the ELS-I was desgined to alleviate uncertainty in making regional scale assessments. Several additional considerations guided the design:

(1) Because all lakes of interest could not be sampled, a subset of lakes was statistically selected from a population of lakes. Because small lakes (<4 ha) could not be included in the sampling frame for a large synoptic survey, they were not included in the population considered.

(2) Sampling and analytical methods were uniform to ensure comparability of data.

(3) Because pH and ANC are ony two of the chemical variables that may be important in understanding lake sensitivity to acidic deposition, many additional variables were measured.

(4) Measurements had to be of known quality; population estimates had to be of known certainty. Therefore, the statistical and analytical methods were well defined and carefully implemented.

(5) Because regional, rather than individual, lake characteristics were the primary focus of the Survey, the ability to make comparisons among lakes rather than within lakes was emphasized in the design.

(6) The ELS-I was designed to provide a data base and establish a statistical basis for selecting subsets of lakes for more detailed study in future phases.

The purpose of this report is to present results obtained from the ELS-I. Results will be used to frame subsequent surveys designed to quantify biological resources and temporal variability in chemistry, and to implement a long-term monitoring program.

The report is organized as follows: Section 2, Methods; Section 3, Quality Assurance; Section 4, Results of Population Estimates; Section 5, Results and Discussion of Associations among Variables; Section 6, Regional and Subregional Characteristics; Section 7, Summary Observations; Section 8, References; and Section 9, Glossary. In addition, reports presenting more detailed information on methods are referenced. Two companion volumes, Volume II: *Lakes Sampled and Descriptive Statistics for Physical and Chemical Variables* and Volume III: *Data Compendium of Site Characteristics and Chemical Variables*, provide the data used to compile this report.

# Section 2
# Methods

## 2.1 Design

### 2.1.1 Data Quality Objectives

Data quality objectives were developed to guide the selection of sampling and analytical procedures for the Eastern Lake Survey - Phase I (ELS-I). These objectives defined goals for precision and bias both for the procedures used in making population estimates and for the methods used in analyzing chemical variables. The data quality objectives guided the statistical design of the Survey, the selection of analytical methods and the design of the quality assurance program (Drouse et al. 1986).

### 2.1.2 Lake Representation

A critical issue in the design of the ELS-I was the representation of a selected lake. If a single water sample can adequately represent the chemistry of a lake to satisfy the specific objectives of a study, a large number of lakes can be sampled. If multiple water samples are needed on a single occasion, then a reduction in the number of sample lakes must be considered. If multiple occasions are needed to represent the chemistry of a single lake, the number of sample lakes must be reduced proportionally.

It is obvious that one sample, from one location, at one time of the day, in a specific season of a particular year, cannot characterize the complex chemical dynamics of a lake. Such a sample is justified only in the sense that it is an *index* to the essential characteristics of the lake. But even if two samples are taken, or three, they remain only indices because understanding the dynamics of a single lake requires far more detailed study. This study was designed to describe populations of lakes. Therefore, each lake must be represented in that population description in a manner that captures its essence, but such that the number of lakes that can be sampled is maximized. The single index sample maximizing both lake number and spatial coverage on a large geographic scale was therefore deemed the most appropriate choice for addressing the collective objectives of the ELS-I.

To enhance the utility of the index sample, careful consideration was given to location and season. The sampling window was designated as the fall season, just after turnover. Spatial variation within the lake is reduced at this time. Sampling at the apparently deepest part of the lake was intended to provide a sample from the dominant water mass. Therefore, the combination of a fall season sampling period and collecting a sample near the lake center at the apparently deepest part, appeared to be the best protocol to provide the needed sampling characteristics.

The perspective that each lake is represented by an index chemistry, rather than, for example, mean chemistry or some other integration over time and space, is important in interpreting the results presented in this report. The population descriptions represent and characterize the chemistry of a population of lakes, as though every lake in the population had been sampled in the same manner as the sampled lakes. Thus the resulting frequency and areal distributions for the chemical parameters (Sections 4.2 and 4.3) represent an index to water mass chemistry for the population of lakes that can be interpreted only through study of the predictive capacity of that index.

Studies of temporal and spatial pattern in a subsample of lakes (Phase II) will provide an opportunity to assess the soundness of these decisions and to evaluate more fully the information that may be gained using the index concept.

### 2.1.3 Statistical Design

The sampling plan for ELS-I employed a stratified design, with equal allocation of number of sample lakes to strata. Three strata were sampled with greater intensity to obtain increased precision (Section 2.2.3). This design is consistent with the objective of describing the populations of lakes within the individual strata with roughly the same precision. Lakes were selected from each stratum by systematic sampling of an ordered list (Section 2.2.2) following a random start.

The choice of sample size, 50 or more target lakes per stratum (Section 2.2.3), was based on the judgment that this sample size was expected to yield adequate precision for the 33 strata in the ELS-I. To evaluate expected precision from various sample sizes, the key statistic was chosen to be $p_c$, the estimated proportion of lakes with a value of the variable X below some reference value, $X_c$ (for example, the percentage of lakes with pH $\leq 6.0$). Within a single stratum, $p_c$ can be estimated by $n_c/n$, where $n_c$ is the number of lakes in the sample that meet that condition, and n is the sample size. Within a single stratum, $n_c$ can be treated as a binomial variable. The variance of the binomial variable is greatest when $p = 0.5$. Assessment of precision at this value yields a worst case condition. The results of the comparative assessment are summarized below, using the normal approximation and a one-sided confidence limit:

| n | Maximum Standard Error (p) | Maximum Upper Confidence Limit |
|---|---|---|
| 100 | 0.0500 | p + 0.082 |
| 60 | 0.0645 | p + 0.106 |
| 50 | 0.0707 | p + 0.116 |
| 40 | 0.0791 | p + 0.130 |
| 30 | 0.0913 | p + 0.150 |

where: Maximum Standard Error (p) = $\sqrt{0.25/n}$

Based on this comparison, the population estimate for the number of lakes within a stratum [F(x) curve (Section 4.3.2.1)] was estimated to be within 12 percent for a sample size of 50. A number of other considerations are involved in actually setting the confidence limits; the above assessment served only as a planning device. It is also of interest that at the sample size of 50, the least upper confidence bound occurs when $n_c$ (the number of lakes meeting the condition defined by $X_c$) is zero, and is within 6 percentage points (0.06).

### *2.1.4 Identification of Study Area*

The population of lakes to be sampled was defined as lakes located within those regions expected to contain the most lakes in the U.S. characterized by alkalinity $<400$ $\mu$eq $L^{-1}$ (i.e., those areas where acidic deposition would potentially have the most effect). For the ELS-1, the boundaries of three regions, judged to contain about 95 percent of the lakes of lower alkalinity in the eastern U.S., were delineated using a national map of surface water alkalinity (Omernik and Powers 1983). The Northeast, the Upper Midwest, and the Southeast, as defined in Figure 2-1, were selected as the study areas in which to conduct the ELS-I.

## 2.2 Lake Selection

### *2.2.1 Delineation of Strata*

The three regions shown in Figure 2-1 represent the first level of stratification in the design. Using region as a stratification factor ensured that each region containing low alkalinity lakes would be adequately represented in the sample.

The second stratification factor, subregion, identified areas within each region that were expected to be relatively homogeneous with respect to water quality, physiography, vegetation, climate, and soils. Based on geographic homogeneity, five subregions (1A-1E) were identified in the Northeast, four (2A-2D) in the Upper Midwest, and two (3A and 3B) in the Southeast (Figures 2-2 to 2-4). Descriptive names of subregions were assigned (Table 2-1). Subregion was used as a stratification factor to ensure that a representative sample was drawn from each geographically distinct portion of a region.

The third stratification factor, alkalinity map class, differentiated among areas within each subregion based on the range of surface water alkalinity values expected to dominate in different areas. The alkalinity map classes chosen were $<100$ $\mu$eq $L^{-1}$ (class 1), 100-200 $\mu$eq $L^{-1}$ (class 2), and $>200$ $\mu$eq $L^{-1}$ (class 3). Spatial representations of the three alkalinity classes within each region were derived from preliminary versions of regional surface water alkalinity maps (Omernik and Kinney 1985; Omernik and Griffith 1985; Omernik 1985). An alkalinity of 200 $\mu$eq $L^{-1}$ has been used (Galloway 1984) as the boundary distinguishing between those surface waters considered to be potentially "sensitive" and those considered "insensitive" to long-term acidification as a result of current levels of acidic deposition. The choice of 100 $\mu$eq $L^{-1}$ was based on evidence that biological effects of acidification might become apparent in the alkalinity range 10-90 $\mu$eq $L^{-1}$ (Haines and Akielaszek 1983).

In summary, each stratum is an alkalinity map class within a subregion within a region. All three alkalinity map classes were found within each of the eleven subregions, so that a total of 33 strata (15 in the Northeast, 12 in the Upper Midwest, and 6 in the Southeast) were defined. The strata are coded by region, subregion, and alkalinity map class. For example, 1A2 designates the Northeast Region, the Adirondack Subregion, and alkalinity map class 2.

### *2.2.2 Development of the Map Population and Frame*

Region, subregion, and alkalinity map class boundaries were delineated and labeled on 1:250,000-scale U.S. Geological Survey (USGS) topographic maps. The lake type, elevation, size, and watershed size were evaluated as potential ordering factors by means of a mapping exercise to check for spatial patterns. The selection and use of these ordering factors as they apply to the generation of the frame (see below) are described in detail in Omernik et al. (1986).

Each lake represented on the maps was then assigned a unique number. Lakes were numbered consecutively within a mapping unit starting in its northwest corner and working east within a strip one to four inches wide, depending on the density of lakes represented on the maps. This process was repeated from north to south until all lakes in the mapping unit were numbered. Lakes in the next mapping unit were then numbered, beginning with the next consecutive number, until the entire stratum was completed. In strata where mapping units were not used, the process was the same as if the entire stratum were one mapping unit. The final number in each stratum was the total number of lakes in the map population for that stratum.

The map population (frame population) represents the universe of lakes considered for study in the ELS-I. All population estimates computed in this study refer to the map population (Section 2.2.4) and do not represent conditions in lakes outside the area of coverage or in systems not depicted on the USGS maps used.

**Figure 2-1.** **Regions and subregions surveyed during the Eastern Lake Survey-Phase I.**

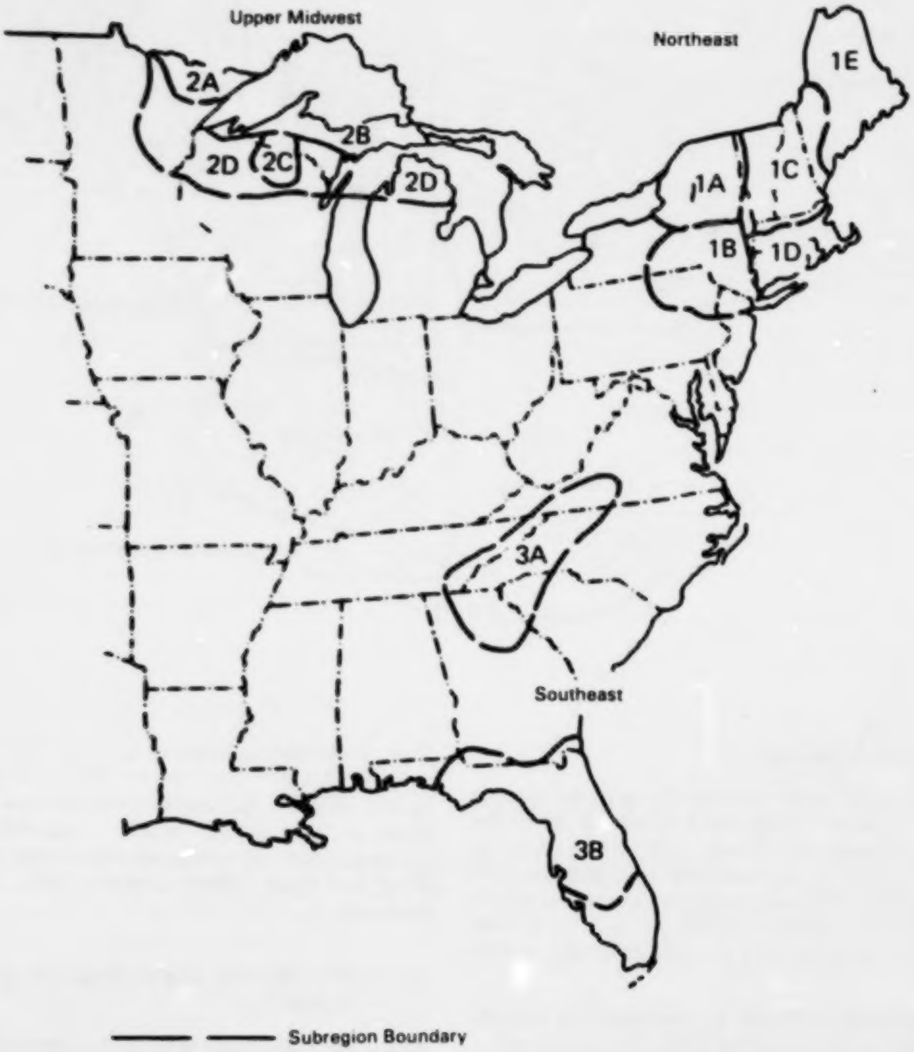
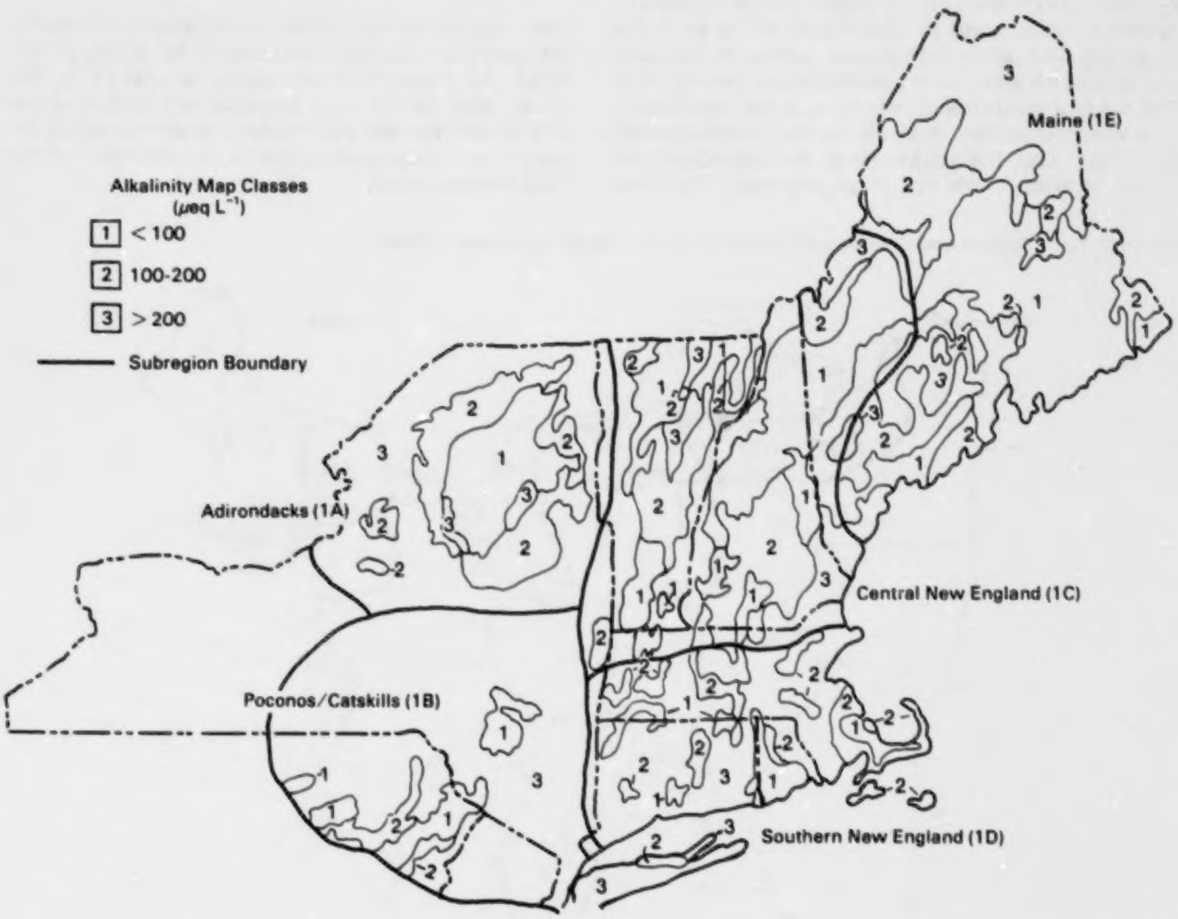


**Figure 2-2. Northeastern subregions and alkalinity map classes, Eastern Lake Survey-Phase I.**


Alkalinity Map Classes
(µeq L⁻¹)
1 < 100
2 100-200
3 > 200
Subregion Boundary
Maine (1E)
Adirondacks (1A)
Central New England (1C)
Poconos/Catskills (1B)
Southern New England (1D)

### 2.2.3 Probability Sample

Within each stratum a systematic random sample was used to select lakes. Lake numbers were entered into a computer file in numerical order as labeled on the maps. In the strata in Subregions 1A, 1C, 1E, and 2A, lakes were in spatial order within ordering factor classes. In the remaining subregions, lakes were simply in spatial order within strata.

For each stratum the map population size was divided by the prescribed sample size to obtain a number (k). The first sample lake was then selected at random between lakes 1 (one) and k. Thereafter, every k$^{th}$ lake was selected. This procedure ensured that each lake in the frame list of a stratum had an equal probability of inclusion.

The prescribed sample size was 50 for all strata except stratum 1A1 within the Adirondacks (60 lakes), stratum 1C1 within Central New England (70 lakes) and stratum 1E1 within Maine (90 lakes). Only 19 lakes occurred within alkalinity map class 1 in the Southern Blue Ridge (stratum 3A1), so all were included.

### 2.2.4 Identification and Refinement of Frame Population

The map population was refined through the elimination of "non-target" lakes. The lakes in the probability sample were examined on 1:24,000-, 1:25,000- or 1:62,500-scale USGS topographic maps. Categories of lakes that were collectively termed non-target lakes included:

(1) *No lake present:* lakes initially identified on 1:250,000-scale maps that did not appear on more detailed, larger-scale maps.

(2) *Flowing water:* sites identified as lakes on 1:250,000-scale maps that appeared as points on a stream on larger-scale maps. However, if the small-scale maps were more recent than the large-scale maps and the lake in question was known to be a new reservoir, it was not eliminated.

(3) *Bay/Estuary (High conductance):* lakes identified on 1:250,000-scale maps that appeared as ocean embayments or estuaries on larger-scale maps.

(4) *Urban/Industrial/Agricultural:* lakes surrounded by or adjacent to intense urban, industrial, or agricultural land use including tailing ponds, water treatment lagoons, fish hatcheries, and cranberry bogs.

(5) *Marsh/Swamp:* lakes identified on 1:250,000-scale maps that appeared as swamps or marshes on larger-scale maps.

(6) *Too small (<4 ha):* lakes identified on 1:250,000-scale maps that were less than approximately four hectares. Because the resolution of most 1:250,000-scale maps was about four hectares, this limit was established for consistency. Lakes less than four hectares are not represented by the population descriptions.

After eliminating non-target lakes by examining maps, additional lakes were selected, when necessary, by applying the same systematic random sampling process to the remaining lakes in the initial list frame. More than the prescribed number of lakes were selected, since it was also anticipated that additional lakes would be eliminated as non-target lakes during field operations. Because the

**Figure 2-3. Upper midwestern subregions and alkalinity map classes, Eastern Lake Survey-Phase I.**

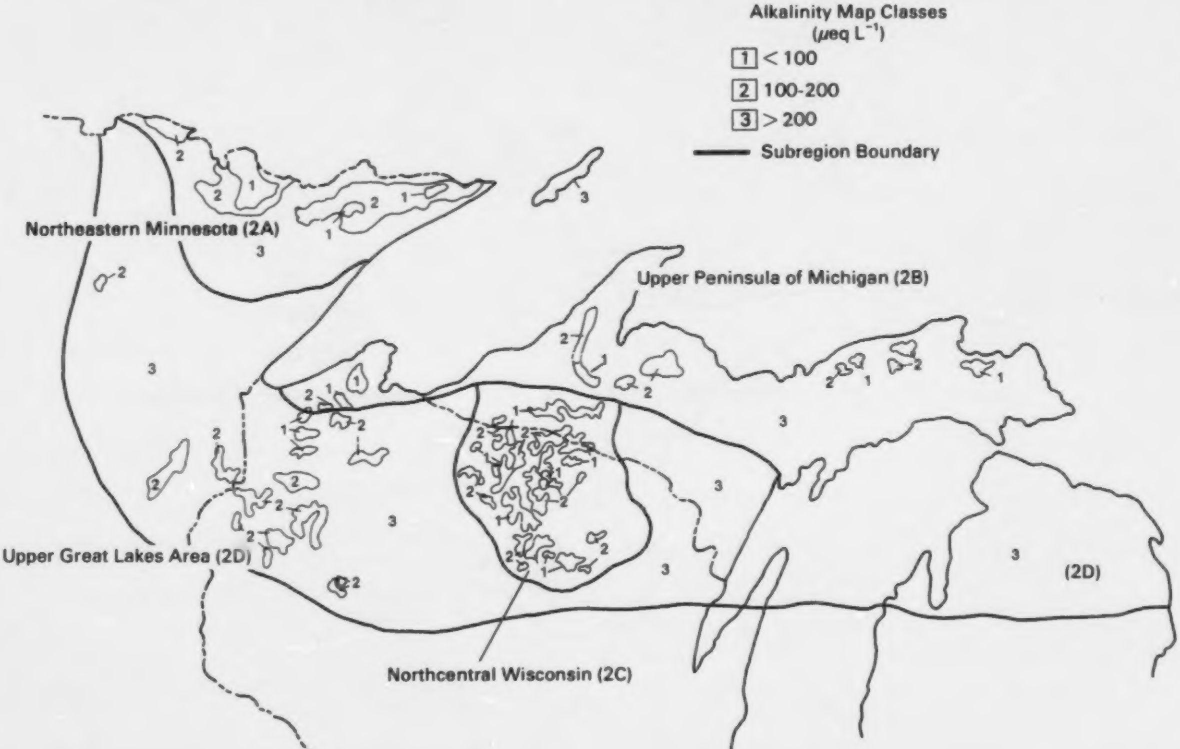

Alkalinity Map Classes
($\mu$eq L$^{-1}$)
1 < 100
2 100-200
3 > 200
Subregion Boundary
Northeastern Minnesota (2A)
Upper Peninsula of Michigan (2B)
Upper Great Lakes Area (2D)
Northcentral Wisconsin (2C)
(2D)
1
2
3

Figure 2-4. Southeastern subregions and alkalinity map classes, Eastern Lake Survey-Phase I.

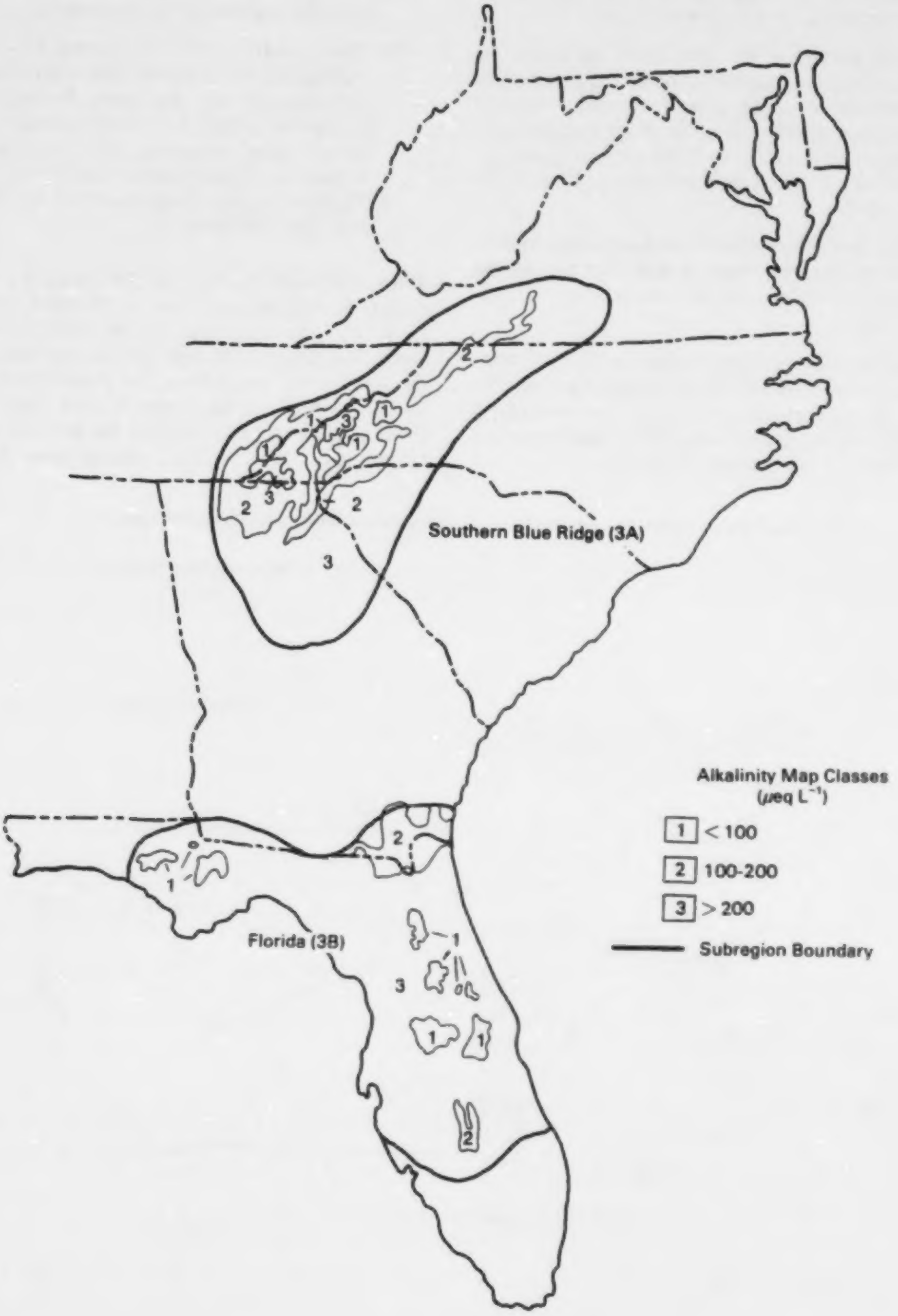

Southern Blue Ridge (3A)
Florida (3B)
1
2
3
Alkalinity Map Classes
(μeq L⁻¹)
1 < 100
2 100-200
3 > 200
Subregion Boundary

**Table 2-1. Assigned Numbers and Names for Regions and Subregions, Eastern Lake Survey - Phase I**

| Region 1: Northeast | Region 2: Upper Midwest | Region 3: Southeast |
|---|---|---|
| 1A: Adirondacks | 2A: Northeastern Minnesota | 3A: Southern Blue Ridge |
| 1B: Poconos/Catskills | 2B: Upper Peninsula of Michigan | 3B: Florida |
| 1C: Central New England | 2C: Northcentral Wisconsin | |
| 1D: Southern New England | 2D: Upper Great Lakes Area | |
| 1E: Maine | | |

number of non-target lakes varied from stratum to stratum, the final number of lakes selected within strata varied.

The remaining lakes were provisionally designated as target lakes with this designation to be further refined as a result of information obtained during field sampling. The categories of non-target lakes eliminated by the field crews included all categories above except the "too small" class. These were defined as:

(1) *No lake present:* lakes visited that were found to be dry.

(2) *Flowing water:* sites visited and found to be streams.

(3) *High conductance:* lakes that, upon visitation, were found to have measured specific conductance >1500 $\mu$S cm$^{-1}$.

(4) *Urban/Industrial/Agricultural:* lakes surrounded by or adjacent to intense anthropogenic activities.

(5) *Too shallow*[2]*:* lakes that were too shallow to obtain a clean (i.e., free of debris or sediment) sample.

(6) *Too small:* this category was not used by field crews (see above categories).

(7) *Other:* lakes that were inaccessible due to a permanent feature of the lake that prevented helicopters from landing safely (e.g., power lines).

Some other lakes in the provisional field sample were not visited, including those that were inaccessible due to bad weather, which were frozen, or to which access permission was denied. These lakes represent incompleteness in the sample and were classified as "not visited" (could not be sampled) only if the reasons for not sampling were unrelated to a permanent feature of the lake. If a lake could not be visited because of a permanent feature such as shallowness, it was classified as non-target. Those lakes not visited because they were frozen, for example, did not warrant non-target classification since this is not a permanent feature of the lake. For statistical analyses, it was assumed that lakes not visited had the same proportion of non-target lakes as those found in the visited lakes. Table 2-2 provides numbers of non-target lakes identified during map examinations and during field sampling, and reasons for their exclusion from the target population. Categories and numbers of lakes classified as not visited are also shown. These definitions collectively identify the populations of lakes about which conclusions can be drawn; they further restrict the interpretation of the results as does the identity of the map/frame population from which the probability sample was drawn.

### 2.2.5 Special Interest Lakes

A number of lakes other than those chosen in the probability sample were sampled during the ELS-I. All lakes in the current EPA Long-Term Monitoring Program, which is also part of the National Acid Precipitation Assessment Program, were included as special interest lakes. Others were included on the basis of recommendations from the Acid Deposition Trends Committee of the National Research Council and from state and federal agencies.

Because these special interest lakes were not chosen by the steps discussed in Section 2.2.3, the data from these lakes were not included in population estimates (Section 2.3.2). They were, however, included in the analyses of associations among variables because such analyses are not prohibited in the application of the design (Section 2.3.4). To differentiate special interest lakes from those in the probability sample, the latter are referred to as "regular" lakes.

### 2.2.6 Final Lake List and Maps

Each selected lake was given a unique identification (ID) number coded by the three levels of stratification. For example, 1A2-034 designated the 34th lake in Subregion A, in Region 1, alkalinity map class 2. Lake ID numbers, lake names, geographical coordinates, and map names were entered into computer

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[2] Original sampling protocols were designed to take samples only from 1.5 m. However, this protocol was modified in the field to allow samples to be taken from 0.5 m in lakes where a 1.5-m clean sample could not be taken, provided a 0.5-m clean sample could be taken (Section 4.2.2).

**Table 2-2. Non-Target and Not Visited Lakes, Eastern Lake Survey - Phase I**

A. Non-target regular lakes determined from large-scale map examination

| CATEGORIES | 1A | 1B | 1C | 1D | 1E | 2A | 2B | 2C | 2D | 3A | 3B | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO LAKE PRESENT | 1 | 2 | 0 | 2 | 1 | 2 | 2 | 0 | 0 | 0 | 6 | 16 |
| FLOWING WATER | 8 | 2 | 5 | 5 | 11 | 3 | 0 | 0 | 1 | 3 | 0 | 37 |
| BAY/ESTUARY | 0 | 0 | 0 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| URBAN/INDUSTRIAL | 0 | 8 | 1 | 29 | 0 | 6 | 0 | 0 | 1 | 11 | 19 | 75 |
| MARSH/SWAMP | 5 | 7 | 4 | 8 | 7 | 1 | 7 | 0 | 9 | 2 | 136 | 185 |
| TOO SMALL (<4 ha) | 23 | 20 | 39 | 47 | 54 | 26 | 68 | 10 | 60 | 44 | 94 | 485 |
| TOTAL | 37 | 39 | 49 | 96 | 75 | 38 | 77 | 10 | 71 | 58 | 255 | 805 |

B. Non-target regular lakes determined from direct examination

| CATEGORIES | 1A | 1B | 1C | 1D | 1E | 2A | 2B | 2C | 2D | 3A | 3B | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO LAKE PRESENT | 2 | 6 | 2 | 4 | 3 | 0 | 4 | 0 | 2 | 9 | 9 | 41 |
| FLOWING WATER | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 3 |
| HIGH CONDUCTANCE | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 7 |
| URBAN/INDUSTRIAL | 2 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 5 |
| TOO SHALLOW | 7 | 4 | 10 | 12 | 17 | 9 | 15 | 6 | 3 | 1 | 5 | 89 |
| OTHER | 1 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 |
| TOTAL | 12 | 12 | 12 | 26 | 21 | 10 | 19 | 7 | 5 | 11 | 16 | 151 |

C. Reasons that regular lakes were not visited

| CATEGORIES | 1A | 1B | 1C | 1D | 1E | 2A | 2B | 2C | 2D | 3A | 3B | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO ACCESS PERMISSION | 1 | 9 | 2 | 9 | 0 | 0 | 0 | 1 | 0 | 8 | 13 | 43 |
| TIME/DISTANCE CONSTRAINTS | 3 | 2 | 5 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 12 |
| BAD WEATHER | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 5 | 0 | 0 | 10 |
| WRONG LAKE | 0 | 1 | 0 | 0 | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 5 |
| HIGH TURBIDITY | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| FROZEN | 0 | 1 | 0 | 0 | 0 | 4 | 8 | 7 | 21 | 0 | 0 | 41 |
| TOTAL | 4 | 13 | 7 | 9 | 2 | 9 | 12 | 8 | 28 | 8 | 13 | 113 |

files, and were used to prepare lists for use by field crews.

The latitude and longitude of each lake were determined with eleven-point dividers to the nearest degree, minute, and second. The original coordinates were plotted by computer on transparent map overlays that were compared to the original maps to confirm further the coordinates of each lake (Section 3.5.1). ID codes were recorded on the topographic maps for use by field crews in locating the lakes.

## 2.3 Applications of the Design

### *2.3.1 Defining the Target Population*

The identity of the map population, subsequently refined by the exclusion of non-target lakes (Section 2.2.4), defines the target population. The number of lakes comprising the target population is not known, but rather estimated, because non-target lakes were identified only in the probability sample. In contrast, the map population, because of its operational definition as all lakes appearing on 1:250,000-scale USGS maps (Section 2.2.2), is known precisely and serves as the point of reference. The map population is larger than the target population by virtue of the exclusion criteria set forth for non-target lakes. The sample frame is the structure imposed on the map population by stratification and generation of the list. The frame population and sample selection are stratum-specific, as is the estimation process. Sample data *must* be weighted by stratum-specific weights when extrapolating from sample results to estimates of population parameters. The method of extrapolating to the population is given in Section 2.3.2 and its importance is discussed in Section 4.1.2.1.

In the broadest sense, the target population is all those lakes appearing on 1:250,000-scale USGS topographic maps that could be sampled to yield data to satisfy the objectives of the ELS-I. However, the inherent flexibility of the design permits any subpopulation of lakes from this overall target population to be defined on the basis of any criteria established from the attributes or measured variables for any lake. The definition of these still smaller populations can be determined to answer a particular question. For example, a subpopulation of interest can be defined as that set of lakes characterized by elevation greater than 300 m. Or the subpopulation might be defined on the basis of sulfate or dissolved organic carbon concentrations greater than or equal to X. Estimates of subpopulation characteristics can be made in the same manner as for the entire target population by applying the proper weights.

### *2.3.2 Estimating the Target Population Size and Associated Variance from Sample Data*

The process of estimating the target population size is illustrated in Figure 2-5. The number of target lakes (N) within an alkalinity map class stratum is estimated by the equation:

$$\hat{N} = N^{*} - \hat{N}_n$$

where:

$N^{*}$ = the number of lakes in the stratum map population, and

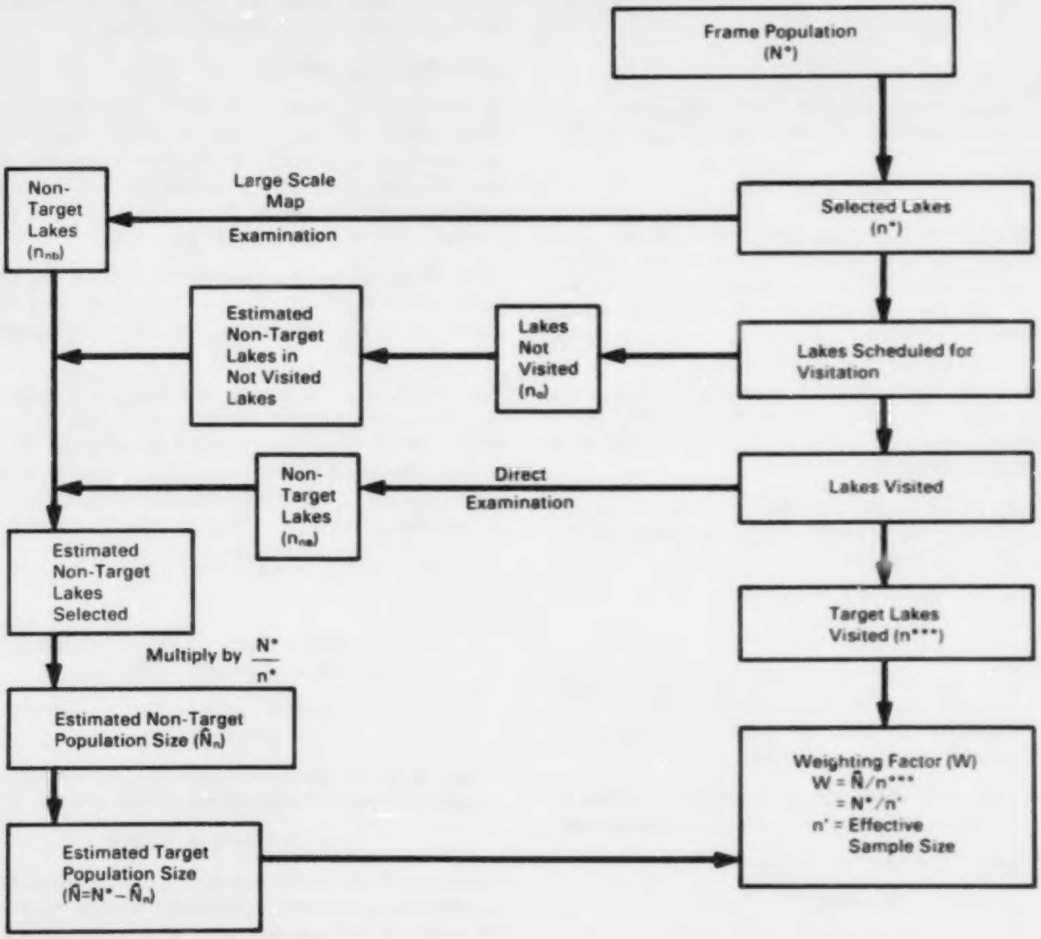
$\hat{N}_n$ = the estimated number of non-target lakes in the stratum map population.

$N^{*}$ is known from the initial map population (Section 2.2.2).

$\hat{N}_n$ must be calculated from the equation:

$$\hat{N}_n = (N^{*}/n^{*})\,[n_{nb} + (n_{na}/q)]$$

**Figure 2-5. Estimating the target population size, Eastern Lake Survey -Phase I.**


Frame Population
(N*)
Selected Lakes
(n*)
Large Scale
Map
Examination
Non-
Target
Lakes
(n_nb)
Lakes Scheduled for
Visitation
Lakes
Not
Visited
(n_s)
Estimated
Non-Target
Lakes in
Not Visited
Lakes
Lakes Visited
Direct
Examination
Non-
Target
Lakes
(n_na)
Estimated
Non-Target
Lakes
Selected
Multiply by N*/n*
Target Lakes
Visited (n***)
Estimated Non-Target
Population Size (N̂_n)
Weighting Factor (W)
W = N̂/n***
= N*/n'
n' = Effective
Sample Size
Estimated Target
Population Size
(N̂=N* − N̂_n)

where:

$n^*$ = the total number of lakes in the probability sample selected from the map population within the alkalinity map class stratum

$n_{nb}$ = the number of lakes selected in the probability sample determined to be non-target by the examination of large-scale maps

$n_{na}$ = the number of lakes in the probability sample determined to be non-target during field sampling

$q = \left(\frac{n^* - n_{nb} - n_o}{n^* - n_{nb}}\right)$ = proportion of completion, i.e., the proportion of lakes selected for visitation that were actually visited.

where:

$n_o$ = the number of lakes not visited, representing incompleteness in the field sampling.

Some of the lakes scheduled for field visitation subsequently were not visited by field crews (Section 2.2.4). The group of lakes that were not visited contained an unknown number of lakes that would be classified as non-target. It was subsequently necessary to expand the number of non-target lakes observed by the field crews ($n_{na}$) by q to yield an estimate of the total number of non-target lakes in the field sample (including the number of non-target lakes expected within $n_o$).

Weighting or expansion factors are necessary to estimate the population of lakes in the target population and are calculated as follows:

$$W = \hat{N}/n^{***} = N^*/n'$$

where:

$n^{***} = n^* - n_{nb} - n_{na} - n_o$, the number of lakes visited and characterized as target, i.e., the number of lakes from which water samples were obtained, and

$n' = n^*q$, the effective sample size, used in place of $n^*$ to account for incompleteness.

Rearranging the equation yields

$$\hat{N} = Wn^{***}$$

The total area of target lakes (A) is estimated similarly:

$$\hat{A} = W\Sigma A_i,$$

with summation over all lakes in the stratum sample.

Variances of $\hat{N}$ and $\hat{A}$, for single strata, are estimated by:

$$\hat{V}(\hat{N}) = [N^*(N^* - n')/(n' - 1)][n^{***}/n'][(n' - n^{***})/n'], \text{ and}$$

$$\hat{V}(\hat{A}) = [N^*(N^* - n')/(n' - 1)][1/n'][\Sigma A^2 - (\Sigma A)^2/n'] \ .$$

For multiple strata, estimates and variances are additive,

$$\hat{N} = \Sigma\hat{N}_h,\ \hat{V}(\hat{N}) = \Sigma\hat{V}(\hat{N}_h),\ \hat{A} = \Sigma\hat{A}_h, \text{ and } \hat{V}(\hat{A}) = \Sigma\hat{V}(\hat{A}_h).$$

Standard errors (of estimates) are the square roots of variances. (To use the above formulae, see Table 4-4, Section 4.2.2, and calculate n′ from $n' = N^*/W$.)

In all analyses, the sample was treated as a simple random sample within strata. The ordering of the lakes and the systematic selection process increase precision over a random sample. Therefore, estimates of precision are conservative.

### *2.3.3 Subpopulations*

Estimations of subpopulation parameters require more structure than the basic population estimates and are generally of more scientific interest. For example, each observed value of X defines a subpopulation of lakes having a value of X ≤ that value (lakes ≤ 300 m, lakes ≤ pH 6.5, etc.).

Estimates and corresponding variances can be constructed for these subpopulations, over any combination of strata if the identification of the subpopulation is explicit.

For economy of computation, the algorithms used in generating all the statistics for the Survey are quite different, but are mathematically identical and best understood by formulae generated as a simple modification of the *single* stratum equations, given in Section 2.3.2:

replace each $n^{***}$ by $n_z$ and each $\Sigma$ by $\Sigma_z$

where:

$n_z$ = the number of sampled lakes in the subpopulation z and

$\Sigma_z$ = the summation over the sample lakes in the subpopulation z.

A useful generalization, appropriate for any subpopulation and any combination of strata, is that

$$\hat{N} = \Sigma W, \text{ and } \hat{A} = \Sigma WA,$$

where summation is over the appropriate subset of sample lakes in the appropriate strata, and where the weights (W) are assigned according to the stratum in which the lake belongs in the map population.

A further generalization, used in the data analyses, leads to similar formulae for mean and variance of any variable, X, over any subpopulation and combination of strata:

$$\text{Mean } (X) = \Sigma WX/\Sigma W, \text{ and Variance}$$
$$(X) = \Sigma WX^2/\Sigma W - (\Sigma WX/\Sigma W)^2 \ .$$

These are estimates of the parameters of the population of lakes defined by the set of sample lakes in the summation, and characterized by the distribution, F(X) (Section 4.3.1).

The importance of the weighting factors cannot be overemphasized. As is shown by example in Section 4.1.2, and stated several times in this report (for example, Section 2.3.2), estimating population parameters, or examining relationships among variables with the expectation that these relationships are representative of the population, from sample data without accounting for weights can lead to erroneous calculations and incorrect interpretation.

### *2.3.4 Restrictions*

The use and interpretation of any data set are restricted by the design, the quality of the data obtained and the sampling protocols. The frame and target populations and the period of sampling are the primary considerations influencing the proper interpretation of the ELS-I data.

The period of sampling restricts conclusions to the fall of 1984. Until Phases II and III are completed, the accuracy of extrapolating the index sample to other times of the year or to other years will not be known.

Additional restrictions result from the sampling frame. Most simply, no conclusions can be drawn for lake populations not included in the original frame. Lakes less than 4 ha in surface area are generally not shown on 1:250,000-scale USGS maps used to establish the frame population. Consequently, the ELS-I omitted lakes less than 4 ha because lakes of this size are generally not represented at this map scale. However, small lakes may represent an important resource that could not be sampled practically or statistically in this study. Therefore, no direct conclusions can be drawn about this population of lakes.

As was noted in Section 2.3.3, it is essential to the accurate interpretation of the data to identify clearly any population for which inferences are made. However, there is considerable flexibility in defining a population to be described if it is a subset of the original target population.

## 2.4 Lake Characterization

Because of their effects on surface water chemistry, lake area and elevation, watershed area, and hydrologic lake type are important variables to consider in interpreting chemical data from lakes. These variables were included in the data base and were measured or determined as described in the following sections.

### *2.4.1 Lake Area and Elevation*

Lake area (in hectares) was measured in duplicate with an electronic planimeter on 1:24,000-, 1:25,000-, or 1:62,500-scale maps. If lake boundaries were included on more than one of these maps, 1:250,000-scale maps were used. Island and swamp areas within the lake shown on the maps were included in the measurement of watershed area (Section 2.4.2) rather than lake area.

When a lake was found to be contiguous with other bodies of water, divided between adjoining maps, or exhibited dissimilar shape at different scales of resolution, the following criteria were used in delineating boundaries:

(1) The boundary of a lake was defined as beginning at the narrowest constriction of its inlet or outlet.

(2) When a portion of a lake was not shown on an adjoining map, the perimeter was estimated using topographic contour lines.

(3) When lakes appeared as two distinct bodies of water on a 1:250,000-scale map, but as one on larger-scale maps, the entire water body was measured as if it were one lake.

The elevation of each lake was recorded in feet from the largest-scale map available and was subsequently converted to meters. When no lake elevation was marked on the map, it was interpolated from topographic contour lines.

### *2.4.2 Watershed Area*

An electronic planimeter was used to measure watershed area. Watershed areas greater than 10 to 15 mi$^2$ (approximately 26 to 39 km$^2$) were measured on 1:250,000-scale maps. For watersheds less than 10 to 15 mi$^2$, measurements were made from larger-scale maps.

In some cases, watersheds were not defined clearly by topography. For example, many lakes in Florida are located in flat terrain. In such instances, watershed boundaries were impossible to determine and were reported as "undefined" in the data base.

### *2.4.3 Lake Type*

Lakes were classified by hydrologic type (Wetzel 1983) through visual examination of their morphology on the largest-scale topographic maps available. "Seepage" lakes were defined as those lakes having no inlet or outlet. "Closed" lakes were those with inlets and no outlets. Lakes with outlets but no inlets or with both were termed "drainage" lakes. A fourth category comprised artificial lakes or "reservoirs".

## 2.5 Water Sample Parameters and Analytical Methodology

Twenty-five primary and secondary water sample parameters were selected for measurement on-site or in analytical laboratories during the ELS-I. Twenty-four are presented in Table 2-3. Data for one parameter, base neutralizing capacity, are being reevaluated (Best et al. 1986) and are not included here.

Measurements were made in situ, within 16 hours of sample collection at a field laboratory, or within 7-28 days at an analytical laboratory. Parameters measured more than once included pH, dissolved inorganic carbon (DIC) and conductance.

Dissolved inorganic carbon and pH were determined in the field laboratory using samples sealed from the atmosphere ("closed system"). Dissolved inorganic carbon and pH were also measured in the analytical laboratory on a sample that was exposed to the atmosphere ("open system"). Additional DIC and pH measurements were made in the analytical laboratory on a sample that had been equilibrated with approximately 300 ppm $CO_2$ in air ("air-equilibrated").

## 2.6 Field Methods

The period of field sampling was from October 7,

**Table 2-3. Principal Chemical and Physical Measurements, Eastern Lake Survey -Phase I**

| Parameter[a] | Laboratory Reporting Units | Required Detection Limits | Intralaboratory Precision Goal % RSD[b] | Maximum Allowable Sample Holding Time - Days (Analytical Lab) | Instrument or Method | Reference (Laboratory Methods)[c] |
|---|---|---|---|---|---|---|
| IN SITU | | | | | | |
| pH | -- | -- | -- | -- | Potentiometer Hydrolab | Morris et al. (1986) |
| Conductance | μS $cm^{-1}$ | -- | -- | -- | Conductivity cell Hydrolab | Morris et al. (1986) |
| Lake Temperature | °C | -- | -- | -- | Thermistor Hydrolab | Morris et al. (1986) |
| Secchi Disk Transparency | m | -- | -- | -- | Secchi disk | Morris et al. (1986) |
| FIELD LABORATORY | | | | | | |
| Laboratory pH, closed system | -- | -- | 0.1 unit | -- | Electrometer Orion model 611 | EPA 150.1 |
| Dissolved Inorganic Carbon, closed system | mg $L^{-1}$ | 0.10 | 10 | -- | Infrared Spectrophotometry Dohrmann DC-80 carbon analyzer | EPA 415.2 (modified) |
| True Color | PCU | 0 | 5 | -- | Comparator Hach model CO-1 | EPA 110.2 (modified) |
| Turbidity | NTU | 2 | 10 | -- | Nephelometer Monitek model 21 | EPA 180.1 |
| ANALYTICAL LABORATORY | | | | | | |
| pH, air-equilibrated | -- | -- | 0.05 unit | 7 | Potentiometer | EPA 150.1 |
| pH, open system | -- | -- | 0.05 unit | 7 | Potentiometer | EPA 150.1 |
| Acid Neutralizing Capacity (ANC) | μeq $L^{-1}$ | 5 | 10 | 14 | Acidimetric Titration modified Gran analysis | Hillman et al. (1986); Kramer (1984) |
| Aluminum (Al) | | | | | | |
| extractable | mg $L^{-1(d)}$ | 0.005 | 10 (>0.010)<br>20 (≤0.010) | 7 | Atomic Absorption Spectroscopy, Furnace on MIBK extract | Hillman, et al. (1986) |
| total | mg $L^{-1(d)}$ | 0.005 | 10 (>0.010)<br>20 (≤0.010) | 28 | Atomic Absorption Spectroscopy, Furnace | EPA 202.2 |

**Table 2-3. Principal Chemical and Physical Measurements, Eastern Lake Survey -Phase I (Continued)**

| Parameter[a] | Laboratory Reporting Units | Required Detection Limits | Intralaboratory Precision Goal % RSD[b] | Maximum Allowable Sample Holding Time - Days (Analytical Lab) | Instrument or Method | Reference (Laboratory Methods)[c] |
|---|---|---|---|---|---|---|
| Calcium (Ca) | mg $L^{-1}$(e) | 0.01 | 5 | 28 | Atomic Absorption Spectroscopy, Flame | EPA 215.1 |
| Chloride ($Cl^-$) | mg $L^{-1}$(e) | 0.01 | 5 | 28 | Ion Chromatography | ASTM (1984);<br>O'Dell et al. (1984) |
| Dissolved Inorganic Carbon, air-equilibrated (DIC) | mg $L^{-1}$ | 0.05 | 10 | 14 | Infrared Spectrophotometry | EPA 415.2 (modified) |
| Dissolved Inorganic Carbon, initial ANC (DIC) | mg $L^{-1}$ | 0.05 | 10 | 14 | Infrared Spectrophotometry | EPA 415.2 (modified) |
| Dissolved Organic Carbon (DOC) | mg $L^{-1}$ | 0.1 | 5 (>5.0)<br>10 (≤5.0) | 14 | Infrared Spectrophotometry | EPA 415.2 |
| Fluoride, total dissolved ($F^-$) | mg $L^{-1}$(e) | 0.005 | 5 | 28 | Ion Selective Electrode | EPA 340.2 (modified) |
| Iron (Fe) | mg $L^{-1}$(d) | 0.01 | 10 | 28 | Atomic Absorption Spectroscopy, Flame | EPA 236.1 |
| Potassium (K) | mg $L^{-1}$(e) | 0.01 | 5 | 28 | Atomic Absorption Spectroscopy, Flame | EPA 258.1 |
| Magnesium (Mg) | mg $L^{-1}$(e) | 0.01 | 5 | 28 | Atomic Absorption Spectroscopy, Flame | EPA 242.1 |
| Manganese (Mn) | mg $L^{-1}$(d) | 0.01 | 10 | 28 | Atomic Absorption Spectroscopy, Flame | EPA 243.1 |
| Sodium (Na) | mg $L^{-1}$(e) | 0.01 | 5 | 28 | Atomic Absorption Spectroscopy, Flame | EPA 273.1 |
| Ammonium ($NH_4^+$) | mg $L^{-1}$(e) | 0.01 | 5 | 28 | Colorimetry (Phenate, automated) | EPA 350.1 |
| Nitrate ($NO_3^-$) | mg $L^{-1}$(e) | 0.005 | 10 | 7 | Ion Chromatography | ASTM (1984);<br>O'Dell et al. (1984) |
| Phosphorous, total (P) | mg $L^{-1}$(d) | 0.002 | 10 (>0.010)<br>20 (≤0.010) | 28 | Colorimetry (Phosphomolybdate, or modification, automated) | USGS I-4600-78 |
| Silica ($SiO_2$) | mg $L^{-1}$(d) | 0.05 | 5 | 28 | Colorimetry (automated) | USGS I-2700-78 |
| Sulfate ($SO_4^{-2}$) | mg $L^{-1}$(e) | 0.05 | 5 | 28 | Ion Chromatography | ASTM (1984);<br>O'Dell et al. (1984) |
| Conductance | µS $cm^{-1}$ | --(f) | 2 | 14 | Conductivity Cell | EPA 120.1 |

[a] Dissolved ions and metals were determined except where noted.

[b] Relative precision (% relative standard deviation) calculated for samples at levels above 10 times instrument detection limits, except for pH.

[c] In situ measurements are outlined in Hillman et al. (1986) and Morris et al. (1986). EPA methods are from U.S. EPA (1983), USGS methods are from Skougstad et al. (1979).

[d] Values converted to µg $L^{-1}$ for data analysis. Required Detection Limits are in mg $L^{-1}$.

[e] Values converted to µeq $L^{-1}$ for data analysis. Required Detection Limits are in mg $L^{-1}$.

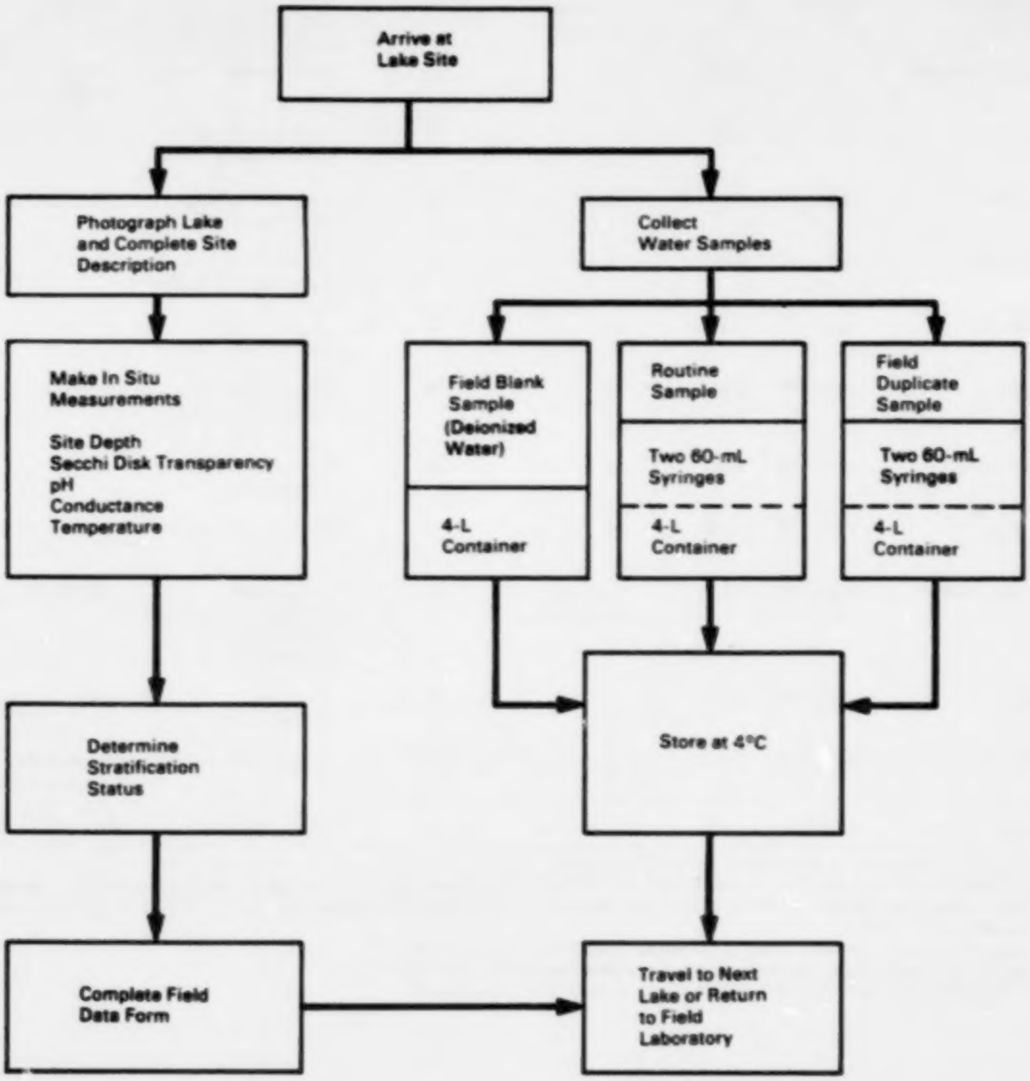
[f] Mean of six nonconsecutive blank values was required to be less than 9 µS $cm^{-1}$.

1984 to December 14, 1984. Lakes were accessed using helicopters with fixed floats. Helicopters landed on the lake and sampling was conducted from the pontoons. Samples were transported to a field laboratory for preliminary processing and preservation before delivery to the analytical laboratories for analysis within required holding times (Table 2-3). The activities conducted by each sampling crew are shown in Figure 2-6. Detailed protocols are described in Morris et al. (1986).

Eight sites were selected as field stations, based on geographic location and the capability to accommodate both helicopters and a field laboratory. Remote base sites were established where necessary to facilitate efficient sample collection. When field crews operated from remote base sites, samples were transferred via aircraft to the field station laboratory for processing.

Field stations were staffed by approximately 15 people, including personnel responsible for logistics, helicopter pilots, field sampling crews, and a field laboratory crew. A two-member sampling

**Figure 2-6.** **Field sampling activities, Eastern Lake Survey -Phase I.**


Arrive at Lake Site
Photograph Lake and Complete Site Description
Collect Water Samples
Make In Situ Measurements
Site Depth
Secchi Disk Transparency
pH
Conductance
Temperature
Field Blank Sample (Deionized Water)
4-L Container
Routine Sample
Two 60-mL Syringes
4-L Container
Field Duplicate Sample
Two 60-mL Syringes
4-L Container
Store at 4°C
Determine Stratification Status
Complete Field Data Form
Travel to Next Lake or Return to Field Laboratory

team visited five to 10 lakes per day by helicopter. Generally, two helicopters were assigned to each field station.

### 2.6.1 Site Description

Lakes to be sampled were identified from the air using a LORAN-C guidance system and USGS topographic maps. Aerial photographs of lakes were taken. Shoreline disturbances and land use (e.g., roads or dwellings) were recorded on a standardized data form. If a lake was accessible by helicopter, the aircraft landed near what appeared to be the deepest portion of the lake. An electronic depth finder was used to locate more precisely the deepest area near where the helicopter landed.

### 2.6.2 In Situ Measurements

Field measurements, recorded on standardized field data forms, included site depth, transparency, pH, temperature, and conductance. Site depth was determined with a weighted sounding line. Transparency was determined with a black and white 20-cm-diameter Secchi disk. The disk was lowered on the shaded side of the aircraft within a calm area between the pontoons.The depths where the disk disappeared upon lowering and reappeared upon raising were recorded and averaged.

In situ measurements of pH, temperature, and conductance were determined using Hydrolab model 4041 units that were retrofitted with glass pH electrodes and Beckman Lazarin reference electrodes. The units were calibrated daily before use with National Bureau of Standards (NBS)-traceable pH buffer solutions (pH = 7.00 and 4.00) and a solution of 0.001 N KCl (specific conductance = 147 $\mu$S cm$^{-1}$). Proper operation of the pH and conductance functions was checked each day before and after sampling activities using a $CO_2$-saturated deionized water solution (theoretical values at STP: pH = 3.91, specific conductance = approximately 50 $\mu$S cm$^{-1}$). The temperature function was checked daily against an NBS-traceable thermometer.

Measurements using the Hydrolab were usually made at 1.5 m (Section 2.6.3). A second set of measurements was made at 1.5 m above the lake bottom. If the temperature difference between top and bottom was <4°C, the lake was classified as nonstratified. If the temperature difference between these two depths was ≥4°C, a third set of measurements was taken at 60 percent of the site depth. If the temperature difference between 1.5 m and 60 percent of the site depth was <4°C, the lake was classified as weakly stratified. If the difference was ≥4°C, the lake was classified as strongly stratified. Temperature and conductance profiles were recorded for all strongly stratified lakes at either 2- or 5-m intervals, depending on site depth (Morris et al. 1986).

### 2.6.3 Collection of Water Samples

Water samples were collected from a depth of 1.5 m if the site depth was >3 m using a 6.2-L Van Dorn acrylic plastic sample bottle (Wildco model 1160-TT). This sampling depth was arbitrary and was selected to be below the influence of the helicopter pontoons and rotor wash. Where the site depth was ≤3 m, samples also were collected at 1.5 m if a clean sample could be obtained. A clean sample was defined as one free from sediment, plants, or other large particulate matter. If a clean sample could not be obtained at 1.5 m, a sample was collected at 0.5 m.

The sampler was modified by installing a nylon Luer-lok fitting to permit collection of sample aliquots in syringes without contacting the atmosphere. Two 60-mL polyethylene syringes were attached, in turn, to the fitting, filled with water, and sealed with locking syringe valves. These were the closed system samples. A bulk water sample was collected by completely filling a 4-L polyethylene Cubitainer from the Van Dorn bottle. Both syringe and bulk water samples were placed in coolers with frozen chemical refrigerant packs and stored at approximately 4°C in the dark until processed at the field laboratory.

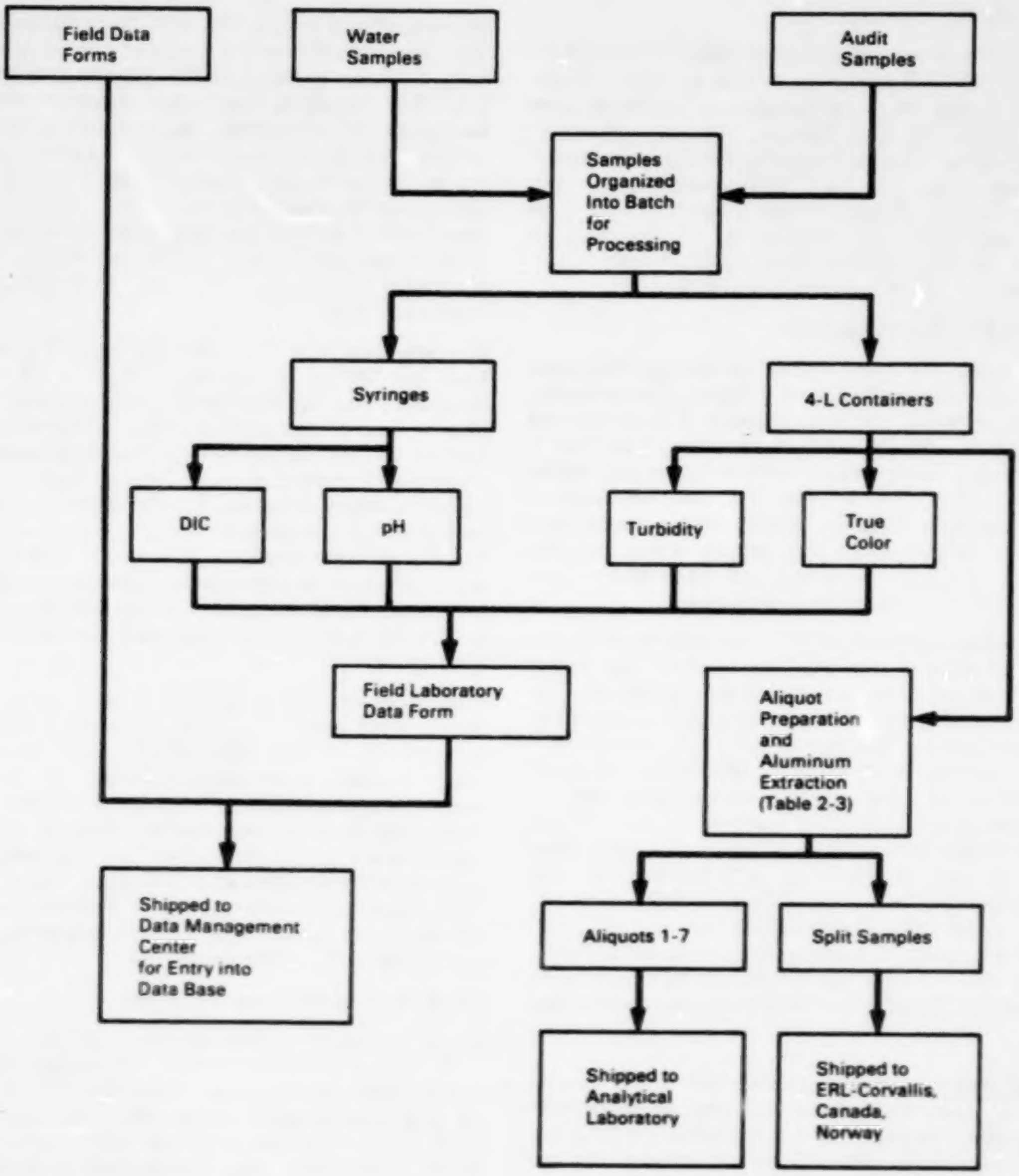
Two types of quality assurance samples were collected. Each sampling crew prepared a field blank sample at the first lake visited each day, using reagent grade water obtained from the deionized water system in the field laboratory (Section 2.6.4). These blanks were prepared by filling the Van Dorn bottle with deionized water and subsequently transferring four liters to a Cubitainer. Once daily, a field duplicate (two syringes and one 4-L Cubitainer) was obtained by collecting a second sample of water from the same lake.

### 2.6.4 Field Laboratory Activities

Field laboratory trailers provided a clean and controlled environment in which to process and preserve water samples and to perform certain chemical analyses as soon as possible after collection. Each laboratory was equipped with a laminar flow hood, a deionized water purification and polishing system, analytical instruments, and equipment for processing and preserving samples. The laboratories and operations (Figure 2-7) are described in detail in Morris et al. (1986) and Hillman et al. (1986).

Upon arrival at each field station, samples were organized into a field batch for processing. A field batch was defined as all the samples (including

**Figure 2-7.** Field laboratory activities, Eastern Lake Survey -Phase I.


Field Data Forms
Water Samples
Audit Samples
Samples Organized Into Batch for Processing
Syringes
4-L Containers
DIC
pH
Turbidity
True Color
Field Laboratory Data Form
Aliquot Preparation and Aluminum Extraction (Table 2-3)
Shipped to Data Management Center for Entry into Data Base
Aliquots 1-7
Split Samples
Shipped to Analytical Laboratory
Shipped to ERL-Corvallis, Canada, Norway

quality assurance samples) that were processed at a given field laboratory on a given day. Each batch and sample was given unique identification numbers to aid in sample tracking. Batch and sample numbers and all analytical data obtained at the field laboratory were recorded on a standardized field laboratory data form.

Dissolved inorganic carbon was measured using a Dohrmann DC-80 carbon analyzer on a filtered (0.45 µm) aliquot from one sealed syringe. The instrument was calibrated daily with a 10.0 mg C $L^{-1}$ standard and checked during the analysis of each batch of samples with a 2.0 mg C $L^{-1}$ solution.

In the field laboratory, pH was measured using an Orion model 611 pH meter with an Orion Ross model 81-52 combination pH electrode. The pH meter allowed for automatic temperature compensation. The pH meter was standardized daily with NBS-traceable buffer solutions (pH 7.00 and 4.00). The operation of the meter was checked during the analysis of each batch of samples with a $10^{-4}$ N $H_2SO_4$ solution (theoretical pH = 4.00).

The pH of the syringe sample was measured at ambient temperature with a pH electrode in a flow-through chamber (Hillman et al. 1986). Because the syringe was connected to the chamber throughout the measurements, injection of the sample from the syringe into this chamber permitted pH to be measured without exposing the sample to the atmosphere. The chamber was rinsed, filled with sample from the syringe, and the pH reading allowed to stabilize. Stabilization was defined as a unidirectional change of 0.02 units or less over a 1-minute period. A 5-mL aliquot of sample was injected into the chamber. The pH of this aliquot was recorded when a stable pH reading was obtained. Additional 5-mL aliquots were injected and the process repeated until two successive, stable measurements agreed within 0.03 pH units. The final pH values was recorded.

Turbidity was determined on subsamples from each Cubitainer using a Monitek model 21 nephelometer. The instrument was calibrated daily with a 10-nephelometric turbidity unit (NTU) standard. The nephelometer was checked during the analysis of each batch of samples with a 5-NTU standard. A second subsample from each Cubitainer was centrifuged for 10 minutes and analyzed for true color using a Hach CO-1 color comparator.

Seven aliquots were routinely prepared from each Cubitainer sample. Table 2-4 summarizes the preparation and preservation requirements and the parameters measured in each aliquot by the analytical laboratories. Certain aliquots were prepared from filtered (0.45 µm Gelman GA Metricel membrane) portions of each bulk sample. Filtration was conducted in the laminar flow hood to minimize potential sample contamination. An aliquot for extractable aluminum (Al) analysis was prepared from a portion of filtered sample, using the method described in Hillman et al. (1986). All extractions were performed within 16 hours of sample collection. Other aliquots were prepared by pouring samples directly from each Cubitainer into appropriate containers. Certain aliquots required preservation with concentrated nitric or sulfuric acid (Baker Ultrex grade or equivalent). All aliquots were stored at about 4°C in the dark until shipment.

Additional aliquots (split samples) were prepared and preserved from each bulk sample for use in

**Table 2-4. Aliquot Preparation and Preservation Requirements, Eastern Lake Survey -Phase I**

| Aliquot | Container[a] | Preparation | Preservation | Parameters |
|---|---|---|---|---|
| 1 | 250-mL Nalgene bottle, acid-leached | Filtered, acid-rinsed filtration unit | Acidified with $HNO_3$ to pH <2; 4°C | Ca, Mg, Na, K, Mn, Fe |
| 2 | 10-mL polycarbonate centrifuge tube | Filtered, 8-hydroxy-quinoline complexation, MIBK extraction | 4°C | Extractable Al |
| 3 | 250-mL Nalgene bottle, leached with deionized water | Filtered, filtration unit not acid-rinsed | 4°C | $Cl^-$, $SO_4^{-2}$, $NO_3^-$, $F^-$, $SiO_2$ |
| 4 | 125-mL Nalgene bottle, acid-leached | Filtered, acid-rinsed filtration unit | Acidified with $H_2SO_4$ to pH <2; 4°C | DOC, $NH_4^+$ |
| 5 | 500-mL Nalgene bottle, leached with deionized water | Unfiltered | 4°C | DIC, pH, conductance, ANC, BNC |
| 6 | 125-mL Nalgene bottle, acid-leached | Unfiltered | Acidified with $H_2SO_4$ to pH <2; 4°C | Total P |
| 7 | 125-mL Nalgene bottle, acid-leached | Unfiltered | Acidified with $HNO_3$ to pH <2; 4°C | Total Al |

[a] All Nalgene made of high-density linear polyethylene.

data comparability studies. Splits from all samples were sent to the EPA Environmental Research Laboratory in Corvallis, Oregon (ERL-Corvallis), for elemental analysis. Other splits were sent to analytical laboratories in Norway and Canada. The results of these analyses will be described in a future report.

Following preparation and preservation, all sample aliquots were refrigerated overnight at 4°C. The following morning, samples were packed in insulated shipping containers with sufficient packages of frozen chemical refrigerants to maintain a temperature of about 4°C during shipment. Samples were shipped to the appropriate analytical laboratory by overnight courier or commercial air freight. A shipping form was used to track samples from the field laboratory to the analytical laboratory. Aliquots arrived at the analytical laboratories within 54 hours of collection. Copies of field and field laboratory data forms were shipped to Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee, for data entry, and to quality assurance staff at the EPA Environmental Monitoring Systems Laboratory in Las Vegas, Nevada (EMSL-Las Vegas). Copies also were sent to the EPA Sample Management Office for sample and data tracking. One copy of each form was retained at the field laboratory.

## 2.7 Analytical Support

Because of the large number of samples and the required holding times, the use of a single laboratory for sample analysis was not possible. For this reason, detailed criteria were prepared that defined the analytical and quality assurance requirements and bids were solicited from analytical laboratories. Prospective laboratories were evaluated through the analysis of performance evaluation samples (Drouse et al. 1986) and on-site inspections.

All analyses were conducted according to handling, analytical, and quality assurance protocols detailed in Hillman et al. (1986) and Drouse et al. (1986). Four analytical laboratories (Table 2-5) were selected. The goal was to analyze all samples collected within one region at the same laboratory; however, due to logistical problems, two laboratories were needed to analyze samples from each region.

## 2.8 Data Base Management

### *2.8.1 Overview*

The objectives of the data management component of the ELS-I were to: (1) enter the data, (2) prepare a validated data set, and (3) perform statistical analysis and evaluation of the data. The Environmental Sciences Division of ORNL designed and implemented data base management activities, using the Statistical Analysis System software (SAS Institute 1982) on tandem IBM 3033 mainframe computers.

**Table 2-5.** **Distribution of Lake Samples to Analytical Laboratories, Eastern Lake Survey -Phase I.**

| Laboratory | Number of Lakes Sampled[a] (% of Total) | Subregion (% of Total) |
|---|---|---|
| Global Geochemistry Corp.<br>Canoga Park, CA | 238 (13.2) | 2A (12.0)<br>2B (28.8)<br>2C (20.3)<br>3A (100) |
| Rockwell International<br>(Environmental Monitoring Services, Inc.),<br>Thousand Oaks, CA | 752 (41.8) | 1A (99.5)<br>1B (50.0)<br>1C (99.5)<br>1D (59.7)<br>1E (100) |
| Versar, Inc.<br>Springfield, VA | 649 (36.1) | 1A (0.5)<br>1B (50.0)<br>1C (0.5)<br>1D (40.3)<br>2A (88.0)<br>2B (71.2)<br>2C (79.7) |
| U.S. Geological Survey<br>Arvada, CO | 159 (8.8) | 3B (100) |

[a] Includes regular and special interest lakes.

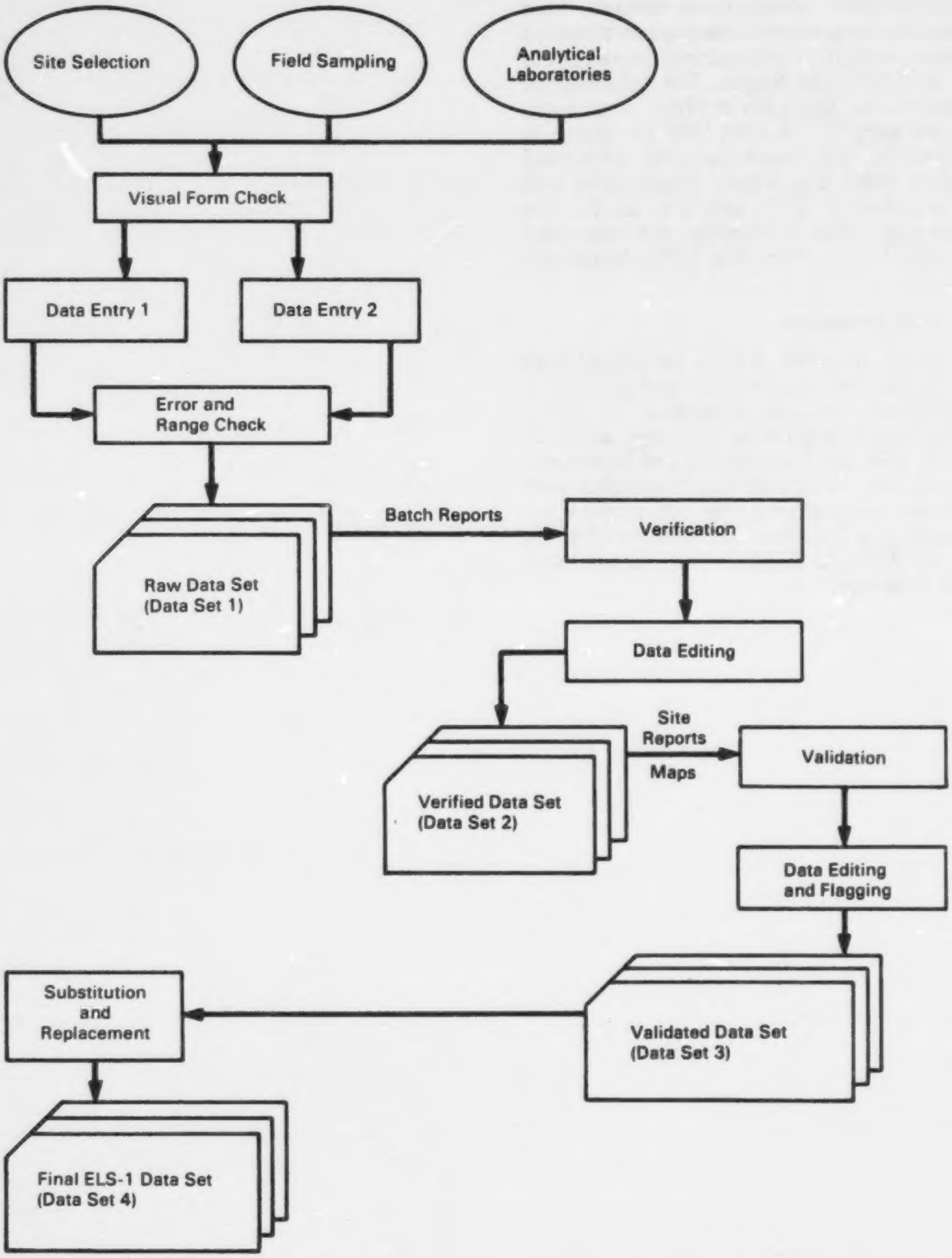
The validated data set consists of individual records for each lake sampled and contains site descriptors, field observations, laboratory measurements, and calculated variables for the lakes sampled. The definition of all variables measured with their formats, units of measure, and comments is presented in a data base dictionary (Kanciruk et al. 1986b). Detailed discussions of the quality assurance measures developed for the data base are given in Rosen and Kanciruk (1985) and Kanciruk et al. (1986a).

### *2.8.2 Data Base Design and Data Flow*

The lake ID assigned before field work began (Section 2.2.6) was used as the key site identifier. The ID numbers were cross-referenced to lake names, state and county Federal Information Processing Standards codes, latitude and longitude, and other identifiers within the site descriptor file.

Data base development is summarized in Figure 2-8. The working data base consisted of three main data sets: raw (Data Set 1), verified (Data Set 2), and validated (Data Set 3). Each contained numerous SAS relational (tabular) data files (SAS Institute 1982). The verified and validated data sets were developed from the raw data set as quality assurance procedures were implemented (Section 3). The final reported data set (Data Set 4) consists of the validated data set, modified after removing erroneous data and substituting for missing values when appropriate (Section 3.4). Protocols used for such changes are discussed in Eilers et al. (1986).

Figure 2-8. Data base development, Eastern Lake Survey--Phase I


Site Selection
Field Sampling
Analytical Laboratories
Visual Form Check
Data Entry 1
Data Entry 2
Error and Range Check
Raw Data Set (Data Set 1)
Batch Reports
Verification
Data Editing
Verified Data Set (Data Set 2)
Site Reports
Maps
Validation
Data Editing and Flagging
Validated Data Set (Data Set 3)
Substitution and Replacement
Final ELS-1 Data Set (Data Set 4)

Copies of all data sets have been maintained on tape as a permanent record.

Background information (lake names, ID numbers and physical characteristics) was transmitted from ERL-Corvallis to ORNL, where it was entered into a data set. Data forms with the information obtained at field sites and analytical laboratories were sent to ORNL and to EMSL-Las Vegas. The information was entered into the data base at ORNL. After entry the data were sent to the EPA IBM computer at Research Triangle Park, North Carolina, for access and review at EMSL-Las Vegas. Corrections and flags were returned to ORNL and entered into the verified data sets. After verification, the data were validated jointly by ERL-Corvallis, EMSL-Las Vegas and ORNL staff.

### *2.8.3 Data Base Structure*

The final data set consists of three relational data files, one each for the regular lakes and special interest lakes and one for all sampled lakes. The information pertaining to each lake, including all background information such as latitude and longitude, country, elevation, as well as the measured variables, has been merged into one observation per lake. In addition, a program for determining the population weighting factors for each stratum (Section 2.3.2) is included.

# *Section 3*
# *Quality Assurance*

Quality assurance (QA) and quality control (QC) procedures for sampling and field and analytical laboratory operations were implemented for the Eastern Lake Survey-Phase I (ELS-I). Development of these procedures required preparation for sampling, implementation of QA/QC activities during field operations, and verification and validation of the data after sample analysis.

## 3.1 Preparation for the Survey

In preparation for lake sampling, a draft QA plan and draft field and laboratory protocols were written and later evaluated during pilot studies (preliminary field studies). The results of these pilot studies were used to evaluate all aspects of the Phase I plans and protocols. The draft plans and protocols were revised based on the results of the pilot studies. The QA plan was developed prior to implementation of the Survey (Drouse et al. 1986). The final field sampling and laboratory protocols were provided to all field personnel. Intensive training was also provided for the field personnel prior to sampling.

## 3.2 Implementation of Quality Assurance/Quality Control Activities

Several QA/QC activities were implemented during field operations. All field stations and analytical laboratories were visited by QA personnel during field operations to evaluate performance and ensure that protocols were being followed. Quality control samples (Table 3-1) were used to assure that instruments and data gathering activities were operating withing limits established by the QA plan. Quality assurance samples (Section 3.5.2) were used to evaluate the performance of field and analytical laboratories and to establish precision estimates. A number of the QA samples were added to the batches in the field and submitted to the analytical laboratories with lake samples. Neither the sample identification nor its composition was disclosed to the analytical laboratory. The relationship of these QA/QC samples to the processing of the lake samples is illustrated in Figure 3-1. Daily contact with the analytical laboratories was made by the QA staff to ensure that appropriate QC protocols were being implemented, and to identify and correct problems if and when they occurred in the laboratory.

The sample data, including QA/QC information, were entered into the raw data set. Data were entered into two separate data files independently. A computer program was developed to compare the two files and identify input errors. The data entry procedure had an estimated error rate of 1 in 6000, or 0.017 percent. After this QC step was completed, errors were corrected and the resulting data were merged into the raw data set.

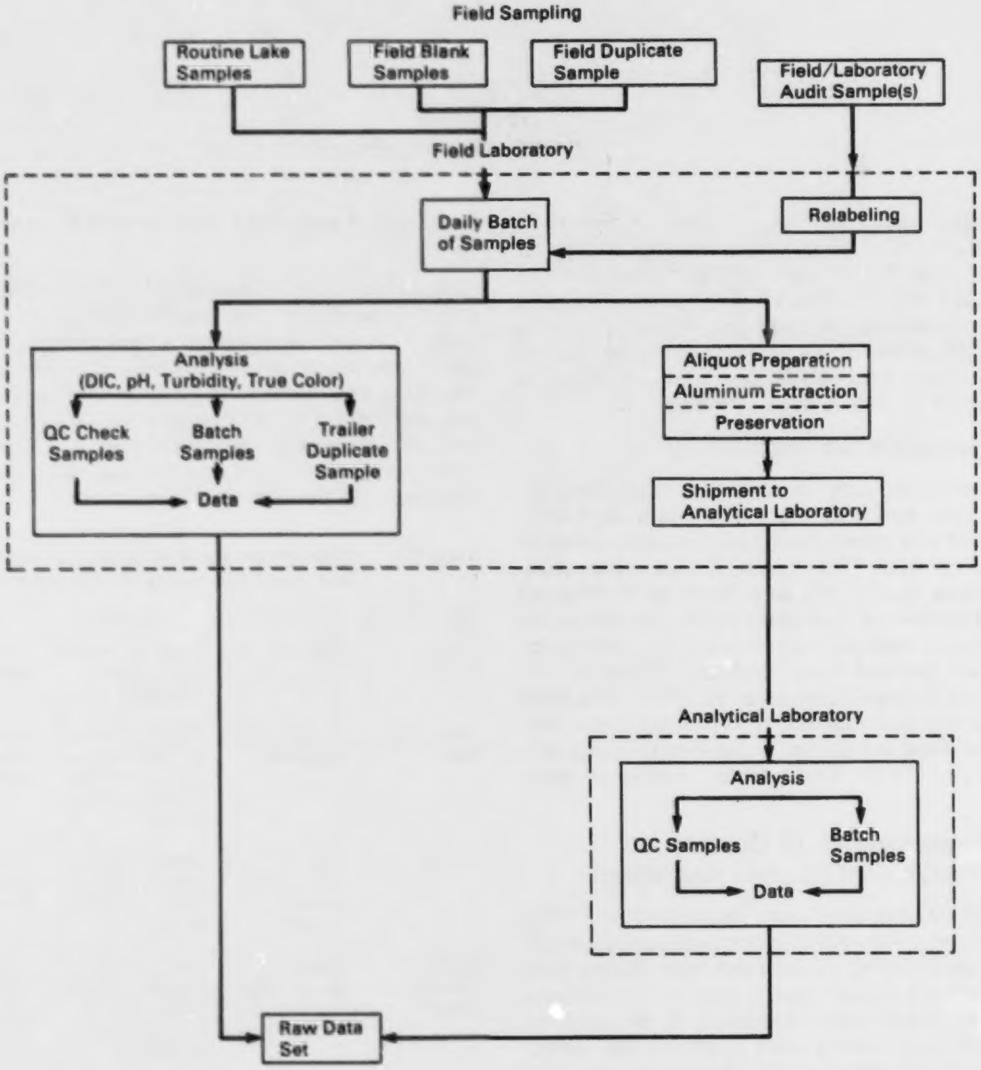
**Table 3-1. Descriptions and Applications of Quality Control Samples, Eastern Lake Survey -Phase I**

| Sample Type | Descriptions | Application | Frequency |
|---|---|---|---|
| Trailer Duplicate | Lake sample; split | Field lab; control within-batch precision | One per field batch |
| Laboratory Blank | Zero analyte standard | Field and analytical lab; control signal drift and sample contamination | One per laboratory batch |
| Matrix Spike | Batch sample plus known quantity of analyte | Analytical lab; control sample matrix effect on analysis | One per laboratory batch |
| Quality Control Check | Standard; source other than calibration standard | Field and analytical labs; control accuracy and consistency of calibration | Before, after every 10, and after final sample |
| Analytical Laboratory Duplicate | Sample aliquot; split | Analytical lab; control within-batch precision | One per laboratory batch |

## 3.3 Data Verification and Validation

Verification of the raw data involved an extensive review of the reported sample data and associated QA/QC information. This review process was used to identify questionable data and to correct, qualify, or eliminate individual values if necesary. The verified data set was validated during data analysis. Details of the verification and validation procedures follow.

Figure 3-1. Collection and processing QA and QC samples, Eastern Lake Survey -Phase I.

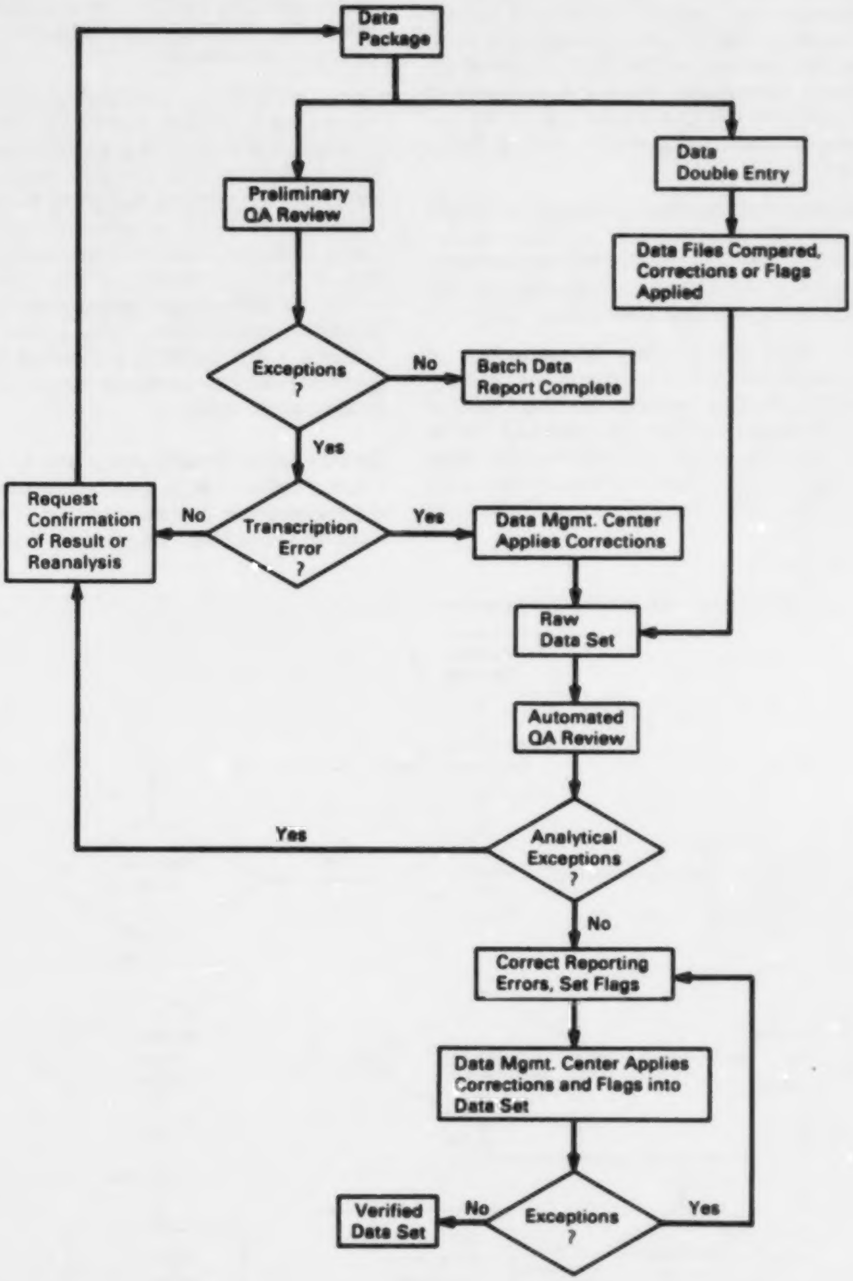

Field Sampling
Routine Lake Samples
Field Blank Samples
Field Duplicate Sample
Field/Laboratory Audit Sample(s)
Field Laboratory
Daily Batch of Samples
Relabeling
Analysis (DIC, pH, Turbidity, True Color)
QC Check Samples
Batch Samples
Trailer Duplicate Sample
Data
Aliquot Preparation
Aluminum Extraction
Preservation
Shipment to Analytical Laboratory
Analytical Laboratory
Analysis
QC Samples
Batch Samples
Data
Raw Data Set

### *3.3.1 Verification*

Data verification was accomplished by establishing a systematic process to identify and review questionable values in the raw data set (Figure 3-2). Data packages, consisting of analytical results and supporting information from the field and analytical laboratories, were sent simultaneously to Oak Ridge National Laboratory (ORNL) for data entry and to the EPA Environmental Monitoring Systems Laboratory (EMSL-Las Vegas) for preliminary review. At these locations, data were checked for completeness and acceptability. Obvious problems with the analytical data were referred to the analytical laboratory for confirmation, correction, or reanalysis of the samples.

After entry into the raw data set, the data were verified on a sample by sample basis. To be verified, data from the analysis of a lake sample had to meet acceptance criteria (Drouse et al. 1986) for both anion-cation balance and percent difference between measured and calculated conductance. Discrepancies were flagged unless they could be

Figure 3-2. Data verification procedures, Eastern Lake Survey -Phase I.


Data Package
Preliminary QA Review
Data Double Entry
Data Files Compared, Corrections or Flags Applied
Exceptions ?
No
Batch Data Report Complete
Yes
Request Confirmation of Result or Reanalysis
No
Transcription Error ?
Yes
Data Mgmt. Center Applies Corrections
Raw Data Set
Automated QA Review
Yes
Analytical Exceptions ?
No
Correct Reporting Errors, Set Flags
Data Mgmt. Center Applies Corrections and Flags into Data Set
Verified Data Set
No
Exceptions ?
Yes

corrected by adjusting a reporting error or could be explained by the presence of dissolved organic protolytes. A protolyte analysis program (Drouse et al. 1986) was used to estimate the relative contributions of carbonates and organic protolytes to acid neutralizing capacity (ANC). Data values for a sample were also flagged when they did not meet acceptance criteria developed from the analysis of external QA samples (Section 3.5.2), internal QC checks, or when prescribed sample holding times were exceeded.

Suspected analytical errors were referred to the analytical laboratory for reanalysis. Data from reanalysis were evaluated (Drouse et al. 1986) and acceptable values were flagged and substituted for the original values in the verified data set.

Less than three percent of the raw data reported for lake samples was classified as exceptions and required correction before transfer to the verified data set. Sample reanalysis was requested for less than one percent of the originally reported raw data values. Less than one percent of the reported data required correction because of transcription or data entry errors

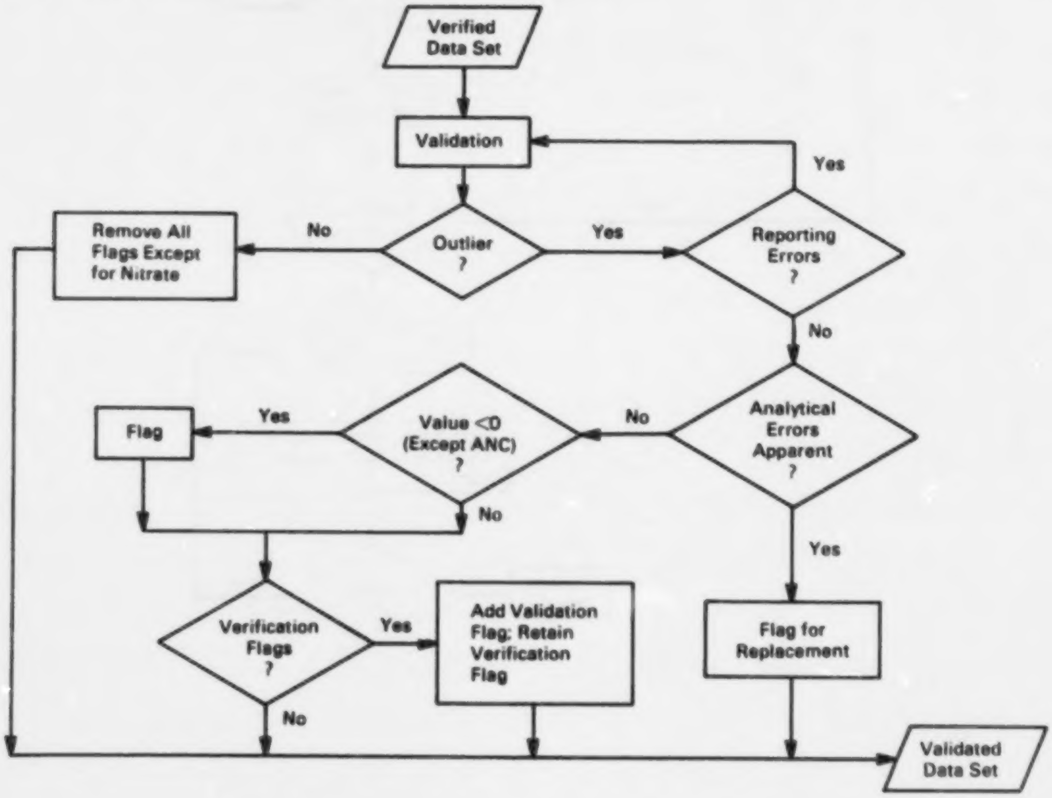
### *3.3.2 Validation*

The data validation process (Figure 3-3) identified possible errors in chemical analyses that could not be revealed by verification procedures (Eilers et al. 1986). The validity of non-chemical measurements was also evaluated.

Observations that were not typical of other sample values, i.e., outliers, were detected using a variety of approaches. Initially, each variable was considered individually to identify values that were outliers with respect to the sample distribution. Boxplots (Tukey 1977) for each variable were prepared using statistical procedures (SAS Institute 1982). These plots summarized the data for a variable using the difference between the upper and lower quartile (interquartile range). For this procedure, outliers were arbitrarily defined as those values greater than the absolute value of three times the interquartile range.

Certain pairs of variables were expected to exhibit a linear relationship. Outliers in these relationships were identified by examination of scatter plots and least squares linear regression analyses. Standard-

**Figure 3-3.** **Data validation procedures, Eastern Lake Survey -Phase I**


Verified Data Set
Validation
Outlier ?
No
Yes
Remove All Flags Except for Nitrate
Reporting Errors ?
Yes
No
Analytical Errors Apparent ?
No
Value <0 (Except ANC) ?
Yes
Flag
No
Yes
Verification Flags ?
Yes
Add Validation Flag: Retain Verification Flag
No
Flag for Replacement
Validated Data Set

ized residual values were calculated using the following formula:

$$\frac{|\text{actual value} - \text{predicted value}|}{|\text{residual standard deviation}|}$$

Values greater than three were identified arbitrarily as outliers. Because least squares analysis can be strongly biased by certain types of outliers (Velleman and Hoaglin 1981), the residuals from resistant line fits (i.e., lines fit through the medians of partitions of data) were examined for selected variables measured in the field and field laboratory. Analytical variables were examined using an iterative process of linear regression to identify additional outliers that would not have been identified without previously removing the major outliers. Outliers among related groups of variables were detected using the SAS FASTCLUS cluster analysis procedure (SAS Institute 1982) and principal components analyses. Possible outliers associated with major cations and anions were examined using trilinear diagrams (Hem 1970). Outliers were screened for agreement with other variables that might explain their high residual standard deviation. Those outliers remaining after confirmation of the reported data were flagged in the validated data set. In a limited number of cases, sufficient evidence was available to indicate that the reported value was in error. These values were flagged in the validated set and marked for substitution in the final data set.

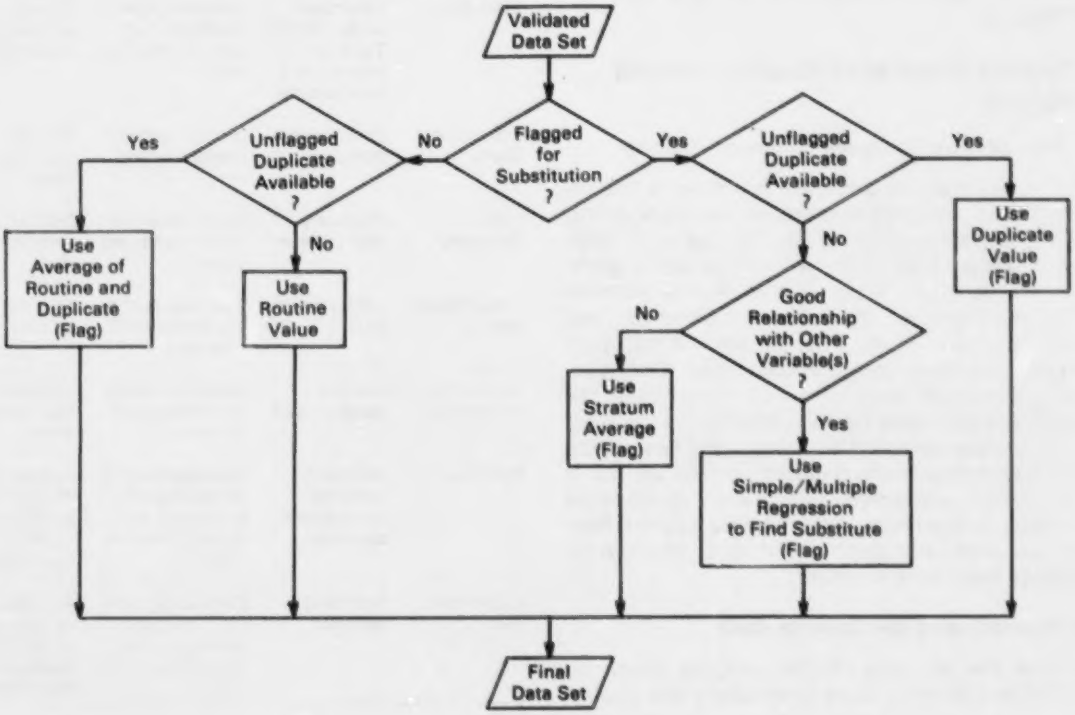
Analytical variables having possible systematic errors were detected by comparing values from the ELS-I to those from other lake survey data sources (Eilers et al. 1986). These data sets were selected on the basis of geographic location, accessibility of the data, and documentation of QA procedures. Comparisons were made using scatter plots and linear regression procedures to identify values requiring additional scrutiny. Systematic differences were not sufficiently large to indicate analytical errors of a magnitude that would affect data analysis and interpretation.

## 3.4 Development of Final Data Set

The calculation of population estimates (Section 2.3.2) is difficult if values are missing from the data set. A final data set (Data Set 4) was prepared to resolve problems in the validated data set resulting from missing values. Data Set 4 also was modified by averaging field duplicate values and substituting for analytical values determined to be in error during validation (Figure 3-4).

Substitution for missing values was done in one of several possible ways. Values from duplicate sam-

**Figure 3-4.** Development of Data Set 4, Eastern Lake Survey-Phase I.


Validated Data Set
Flagged for Substitution ?
No
Yes
Unflagged Duplicate Available ?
Yes
No
Use Average of Routine and Duplicate (Flag)
Use Routine Value
Unflagged Duplicate Available ?
Yes
No
Use Duplicate Value (Flag)
Good Relationship with Other Variable(s) ?
No
Yes
Use Stratum Average (Flag)
Use Simple/Multiple Regression to Find Substitute (Flag)
Final Data Set

ples were used when available. Redundant analyses were performed for pH, DIC, and conductance (Section 2.5). Redundant measurements on split samples (Section 2.6.4) were performed for metals and other elements. If a duplicate measurement was not available, a comparable measurement was chosen and substituted for the missing value using a linear regression routine. If redundant measurements were not available or acceptable, a substitution value was calculated from the available data using observed relationships with other variables (e.g., sodium and chloride). The last option for identifying a substitution value was to use the stratum mean. All substitution values were examined a second time for acceptability before including them in the final data set. Substituted values were flagged as such in the final data set. A total of 145 values of approximately 45,000 chemical measurements examined during the validation process was substituted in the final data set. Of these 145 values, 15 were missing from the data collection process and 130 values were substituted for suspected measurement errors.

Two other changes were made in the final data set. If duplicate data met QA precision criteria, the average of the duplicates was used in the final data set. Negative values for parameters other than ANC, that resulted from analytical calibration bias, were set equal to zero. The bias in the estimate of variance due to this adjustment did not affect data analyses. All values modified in the final data set were flagged.

## 3.5 Quality Assurance/Quality Control Results

### *3.5.1 Site Confirmation and Characterization*

Confirmation that the sampled lakes were the intended lakes was accomplished by comparing aerial photographs taken during the Survey to topographic maps. Five lakes were mistakenly sampled. The data from these lakes were deleted from the final data set and the lakes classified as "not visited" (Section 2.2.4). Five additional samples were also removed from the data base. One lake, Quabbin Reservoir, was sampled twice; only the sample from the major basin is retained in the files. Two lakes were sampled with conductance values exceeding the maximum criterion of 1500 µS cm$^{-1}$. Two additional unnamed lakes were identified as target lakes on the maps, were sampled by the field crews, but were later determined to be affected by discharges from waste outfalls.

### *3.5.2 Evaluation of QA Sample Data*

Data from the analysis of QA samples from the ELS-I (Table 3-2) were used to estimate the quality of the analytical measurements (Best et al. 1986). Field blanks were used to estimate the background value for each parameter. The system decision limit (SDL) represents the lowest measured sample value that can be distinguished from blanks. For the purpose of this report, this value was chosen to be the 95th percentile of the distribution of field blank measurements (Table 3-3). The SDL should not be confused with the laboratory detection limit. The latter evaluates only the analytical method detection limit while the SDL also includes potential contamination from sampling, processing and shipping.

The units for cations (calcium, magnesium, sodium, potassium, and ammonium) and anions (sulfate, nitrate, chloride, and fluoride) are presented in both concentration units as reported from the laboratories (mg L$^{-1}$) and the units used for data analysis (µeq L$^{-1}$), shown in parentheses.

Field blanks were also used to calculate the quantitation limit, which was ten times the standard deviation of field blank measurements. The quantitation limit defines the concentration of an analyte that is high enough to be meaningful for estimating the precision of the sampling and analysis processes.

**Table 3-2.** **Descriptions and Applications of Quality Assurance Samples, Eastern Lake Survey - Phase I.**

| Sample Type | Description | Application | Frequency |
|---|---|---|---|
| Field Blank | Deionized water (ASTM Type 1) treated as a lake sample | Estimate system decision limit and quantitation limit | One per sampling crew per day |
| Laboratory Blank | Zero analyte standard | Identify sample contamination | One per laboratory batch |
| Field Duplicate | Duplicate lake sample | Estimate overall within-batch precision | One per field station per day |
| Trailer Duplicate | Lake sample; split | Estimate analytical within-batch precision | One per field batch |
| Laboratory Duplicate | Sample aliquot; split | Estimate analytical within-batch precision | One per laboratory batch |
| Field Audit | Synthetic samples, natural lake samples | Estimate overall among-batch precision; estimate laboratory bias | A minimum of one field or laboratory audit per field batch |
| Laboratory Audit | Synthetic samples | Estimate analytical among-batch precision; estimate laboratory bias | A minimum of one field or laboratory audit per field batch |

**Table 3-3. Evaluation of Field Blank Data, Eastern Lake Survey-Phase I**

| Parameter (Unit) | System Decision Limit[a] (n = 245) |
|---|---|
| ANC (μeq $L^{-1}$) | 6.9 |
| Conductance (μS $cm^{-1}$) | 1.3 |
| DIC, open system (mg $L^{-1}$) | 0.42 |
| DIC, air-equilibrated (mg $L^{-1}$) | 0.28 |
| DOC (mg $L^{-1}$) | 0.4 |
| Ca (mg $L^{-1}$) | 0.03 (1.5) |
| Fe (μg $L^{-1}$) | 22 |
| K (mg $L^{-1}$) | 0.02 (0.4) |
| Mg (mg $L^{-1}$) | 0.01 (0.7) |
| Mn (μg $L^{-1}$) | 11 |
| Na (mg $L^{-1}$) | 0.03 (1.2) |
| $Cl^-$ (mg $L^{-1}$) | 0.08 (2.3) |
| $SO_4^{-2}$ (mg/$L^{-1}$) | 0.09 (1.9) |
| $NO_3^-$ (mg/$L^{-1}$) | 0.389 (6.3)[b]<br>0.023 (0.4)[c]<br>0.919 (14.8)[d] |
| $F^-$, total dissolved (mg $L^{-1}$) | 0.005 (0.3) |
| $NH_4^+$ (mg $L^{-1}$) | 0.04 (2.1) |
| Al, extractable (μg $L^{-1}$) | 8 |
| Al, total (μg $L^{-1}$) | 30 |
| $SiO_2$ (mg $L^{-1}$) | 0.11 |
| P, total (μg $L^{-1}$) | 8 |

[a] Values in parentheses are in μeq $L^{-1}$.

[b] Value is for analyses of aliquot 3 after protocol change and aliquot 5 before protocol change (n = 245, Section 3.5.2).

[c] Value is for analyses of aliquot 3 after protocol change (n = 99, Section 3.5.2).

[d] Value is for analyses of aliquot 5 (n = 146, Section 3.5.2).

Measurement of sample concentrations less than this value will have higher variability or poorer precision. Because variability increases substantially as the concentration approaches zero, only values above the quantitation limit were used to estimate precision.

Laboratory blank data also were used to judge analytical laboratory performance (Drouse et al. 1986). Laboratory blank values were compared to field blank measurements to identify possible sample contamination that occurred during sample collection, processing, and shipment. The reported instrumental detection limits (Best et al. 1986) indicated that the required detection limit (RDL) was achieved for all parameters except iron. Reanalysis for iron was requested for those samples where the RDL was not achieved. This reanalysis was performed by the alternate graphite furnace method (Hillman et al. 1986), which had an acceptable detection limit.

Data from the analyses of 125 field duplicate sample pairs collected during the ELS-I were used to estimate overall within-batch precision, which included the variability introduced as a result of sample collection, processing, and analysis. Analytical within-batch precision was also estimated using 118 trailer duplicate pairs and 127 laboratory duplicate pairs. The estimates of overall and analytical within-batch precision did not include the effect of among-batch variation that may have been caused by day-to-day differences such as different calibration curves.

Estimates of overall and analytical within-batch precision for field laboratory and analytical laboratory measurements are presented in Table 3-4. Precision estimates for field laboratory measurements were calculated using all available duplicate data, regardless of measurement value. Precision estimates for measurements performed in the analytical laboratories were calculated using duplicate pairs having mean values greater than the quantitation limit. Quantitation limits could not be calculated for field laboratory measurements because field blanks were not measured in the field laboratory; and therefore, some values less than the quantitation limit were included.

For all four field laboratory measurements (Table 3-4), the analytical within-batch precision was better than the intralaboratory precision goals established for the ELS-I. Overall within-batch precision of the pH measurements was also better than expected intralaboratory goals. Overall precision estimates for DIC and turbidity measurements were within expectations for interlaboratory precision (estimated as twice the value of intralaboratory precision). Analytical within-batch precision estimates (pooled across all analytical laboratories) were better than the intralaboratory precision goal for all measurements except air-equilibrated pH, conductance, chloride, sulfate, and extractable aluminum. The precision for air-equilibrated pH, extractable aluminum and sulfate was within the expectation for interlaboratory precision (estimated as twice the intralaboratory precision goal). With the exception of chloride, DOC (>5 mg $L^{-1}$), nitrate, and total aluminum (>0.010 mg $L^{-1}$), overall within-batch precision for measurements made in the analytical laboratories was within the expectation for interlaboratory precision.

Among-batch (interlaboratory) precision cannot be estimated from the field duplicate and analytical laboratory duplicate data because these pairs were not divided among the analytical laboratories. However, audit sample data can be used to estimate interlaboratory precision. Table 3-5 presents the among-batch precision estimated from 41 field natural audit samples. A detailed evaluation of among-batch precision for the ELS-I is presented in Best et al. (1986).

During the early part of the ELS-I, unacceptable levels of nitrate were reported for field blank samples, resulting in non-systematic bias in the nitrate analyses. This contamination was traced to the field laboratory. It was attributed to residual nitric acid from

**Table 3-4.** Estimated Within-Batch Precision from Field, Trailer and Laboratory Duplicate Data, Eastern Lake Survey -Phase I

| Parameter | Intralaboratory Precision Goal %RSD[a] | Overall Within-Batch Precision (Field Duplicates) | | Analytical Within-Batch Precision (Trailer/Laboratory Duplicates) | |
|---|---|---|---|---|---|
| | | n[b] | RMS of %RSD[c] | n[b] | RMS of %RSD[c] |
| **Field Laboratory** | | | | | |
| pH, closed system | 0.1[d] | 124[e] | 0.04 | 93[e] | 0.01 |
| DIC, closed system | 10 | 123[e] | 16 | 116[e] | 4.6 |
| True Color | 10 | 125[e] | 22 | 118[e] | 1.5 |
| Turbidity | 10 | 125[e] | 19 | 117[e] | 8.4 |
| **Analytical Laboratory** | | | | | |
| pH, open system (initial ANC) | 0.05[d] | 125[e] | 0.05 | 127[e] | 0.04 |
| pH, air equilibrated | 0.05[d] | 125[e] | 0.09 | 127[e] | 0.08 |
| ANC | 10 | 90 | 10 | 86[f] | 2.1[f] |
| Conductance | 1 | 125 | 1.9 | 123 | 10 |
| DIC, open system | 10 | 85 | 3.7 | 113 | 3.5 |
| DIC, air equilibrated | 10 | 94 | 5.0 | 94 | 2.2 |
| DOC | | | | | |
| ($\leq$5 mg L$^{-1}$) | 10 | 46 | 5.6 | 73 | 2.5 |
| (>5 mg L$^{-1}$) | 5 | 59 | 12 | 41 | 2.4 |
| Ca | 5 | 125 | 2.3 | 123 | 0.88 |
| Fe | 10 | 32 | 10 | 101 | 4.3 |
| K | 5 | 82 | 3.7 | 121 | 1.5 |
| Mg | 5 | 125 | 2.3 | 121 | 0.64 |
| Mn | 10 | 6 | 11 | 73 | 1.7 |
| Na | 5 | 121 | 4.3 | 121 | 0.96 |
| Cl$^-$ | 5 | 85 | 17 | 124 | 7.1 |
| SO$_4^{-2}$ (mg/L$^{-1}$) | 5 | 115 | 6.5 | 124 | 11 |
| NO$_3^-$ (mg/L$^{-1}$) | 10[g] | 5 | 60 | 86 | 3.6 |
| | 10 | 9 | 45 | 39 | 3.7 |
| | 10 | 0 | -- | 46 | 3.3 |
| F$^-$, total dissolved | 5 | 62 | 8.9 | 123 | 2.5 |
| NH$_4^+$ (mg L$^{-1}$) | 5 | 0 | --[h] | 54 | 2.3 |
| Al, extractable | | | | | |
| (>0.10 mg L$^{-1}$) | 10 | 9 | 11 | 45 | 18 |
| ($\leq$0.10 mg L$^{-1}$) | 20 | 0 | -- | 0 | -- |
| Al, total | | | | | |
| (>0.10 mg L$^{-1}$) | 10 | 1 | 24[i] | 9 | 5.4 |
| ($\leq$0.10 mg L$^{-1}$) | 20 | 0 | -- | 0 | -- |
| SiO$_2$ | 5 | 50 | 2.7 | 64 | 2.2 |
| P, total | | | | | |
| (>0.10 mg L$^{-1}$) | 10 | 4 | 9.7 | 95 | 10 |
| ($\leq$0.10 mg L$^{-1}$) | 20 | 0 | -- | 9 | 8.6 |

[a] RSD = relative standard deviation.

[b] n = number of duplicate pairs with mean > quantitation limit (Best et al. 1986).

[c] Calculated as the root mean square (RMS) of the relative standard deviation of the duplicate pairs (for pH, RMS of the absolute standard deviation was calculated).

[d] Absolute standard deviation (pH unit).

[e] n = total number of duplicate pairs.

[f] Analytical laboratories were not required to analyze calibration blanks for ANC. Values for routine and duplicate pairs with means greater than the quantitation limit (56.6 μeq L$^{-1}$) were calibrated using field blanks.

[g] The first value is for analyses of aliquot 5 and aliquot 3 after the protocol change; the second value is for aliquot 3 only; and the third for aliquot 5 only (Section 3.5.2).

[h] All pairs had mean values $\leq$ quantitation limit. For all pairs with mean >0 (n = 113), the precision was 34%.

[i] Only pair had mean quantitation limit; therefore, the calculated precision (RMS of %RSD) for that pair was equivalent to the actual %RSD. For all pairs with mean >0 (n = 125), the precision was 35%.

the solution used to rinse the filtration apparatus prior to sample preparation. To eliminate this source of contamination, the procedure was changed to use a separate filtration unit to collect aliquot 3 (Section 2.6.4, Table 2-4) for anion analyses. This filtration unit was not rinsed with nitric acid at any time. Nitrate concentrations measured in field blanks prepared using the modified procedure were <0.2 μeq $L^{-1}$. Nitrate data from samples analyzed before the modified protocol was implemented were not used. They were replaced with values obtained by analyzing the corresponding aliquot 5 samples (which were not filtered or preserved with acid) for nitrate after filtration of the samples at the analytical laboratory. Table 3-3 provides decision limits for nitrate as the variable appears in the data base for both the reanalyzed samples (from aliquot 5) and samples analyzed after the protocol was modified (aliquot 3). The second value given is for analysis of aliquot 3 after corrective action was taken. The third value shown is for analysis of aliquot 5. Results of QA sample evaluation for nitrate are presented in Best et al. (1986). Other minor problems involving sample contamination that were identified and resolved through the implementation of the QA program are also summarized in that report.

**Table 3-5. Among-Batch Precision Estimated from Field Natural Audit Samples, Eastern Lake Survey-Phase I**

| Parameter (Unit) | Mean Concentration[a] (n = 41) | Standard Deviation |
|---|---|---|
| pH, open system (initial ANC) | 5.07 | 0.04 |
| pH, air-equilibrated | 5.18 | 0.27 |
| ANC (μeq $L^{-1}$) | (2.36)[b] | 6.1 |
| Conductance (μS $cm^{-1}$) | 26.7 | 1 |
| DIC, open system (mg $L^{-1}$) | 0.42[b] | 0.11 |
| DIC, air equilibrated (mg $L^{-1}$) | 0.19[b] | 0.11 |
| DOC (mg $L^{-1}$) | 3.3 | 0.3 |
| Ca (mg $L^{-1}$) | 1.91 (95) | 0.2 |
| Fe (μg $L^{-1}$) | 21[b] | 14 (13.8) |
| K (mg $L^{-1}$) | 0.49 (13) | 0.02 |
| Mg (mg $L^{-1}$) | 0.35 (29) | 0.01 |
| Mn (μg $L^{-1}$) | 70[b] | 18 |
| Na (mg $L^{-1}$) | 0.67 (29) | 0.03 |
| $Cl^-$ (mg $L^{-1}$) | 0.61 (17) | 0.31 |
| $SO_4^{-2}$ (mg $L^{-1}$) | 6.95 (145) | 0.51 |
| $NO_3^-$ (mg $L^{-1}$) | 1.425 (23)[c] | 0.08[c] |
|  | 1.473 (24)[d] | 0.04[d] |
|  | 1.403 (23)[e] | 0.07[e] |
| $F^-$, total dissolved (mg $L^{-1}$) | 0.077 (4) | 0.003 |
| $NH_4^+$ (mg $L^{-1}$) | 0.06 (3)[b] | 0.03 |
| Al, extractable (μg $L^{-1}$) | 182 | 62 |
| Al, total (μg $L^{-1}$) | 305 | 85 |
| $SiO_2$ (mg $L^{-1}$) | 4.33 | 0.[illegible] |
| P, total (μg $L^{-1}$) | 2[b] (0.0016) | 2 (0.0023) |

[a] Values in parentheses are in μeq $L^{-1}$.

[b] Values are less than quantitation limit (Best et al. 1986).

[c] Values are for analyses of aliquot 3 after protocol change and aliquot 5 before protocol change (n = 41, Section 3.5.2).

[d] Values are for analyses of aliquot 3 (n = 13) after protocol change (Section 3.5.2).

[e] Values are for analyses of aliquot 5 (n = 27, Section 3.5.2).

# Section 4
# Results of Population Estimates

## 4.1 Data Presentation and Considerations

### *4.1.1 Presentation*

In the interest of condensing the results, all tables except those describing the sample and target population (Section 4.2.3) show combined results at the regional and subregional population levels, omitting the results of the alkalinity map class strata (Section 2.2.1). Summaries of regional population estimates are provided for Regions 1 and 2, but not for Region 3. The lakes in Subregions 3A and 3B were found to be so dissimilar that it would be misleading to combine the results from these subregions to obtain regional estimates. For the same reason, population estimates for regions are not combined.

Only the primary variables (pH, ANC, sulfate, calcium, extractable Al and DOC) are summarized by extensive tables in this section. Of the variables measured, these were selected because of their direct relevance to issues of acidic deposition effects. Lake population statistics are also provided for estimates of the physical attributes of the lakes sampled, as well as for secondary variables of interest. Relationships among variables are discussed in Section 5. Volume II of this report gives summary statistics on all the variables measured.

The results of the Survey describe the chemical status of the lakes by comparing cumulative frequency distributions of lake populations (Section 4.3) among and within regions. An assumption implicit in these analyses is that chemical differences among populations ultimately can be attributed to: (1) characteristics of the watershed; and (2) the chemistry of deposition. However, lakes also are chemically altered by anthropogenic disturbances that cannot be ascertained from evaluation of watershed land use types. For example, addition of lime $Ca(HCO_3)_2$ to a lake will dramatically modify the lake ANC, but the nature of the alteration may be undetected in a synoptic survey. Modification of lake chemistry as a result of liming is not random among subregions, being performed predominantly on (formerly) acidic lakes. The magnitude of this and other confounding effects is not known.

### *4.1.2 Design Considerations*

#### 4.1.2.1 Design Constraints

The design of the ELS-I requires that the results be presented as population and/or subpopulation estimates whenever conclusions combining strata are to be drawn (Section 2.3.3). As noted throughout this report, expansion factors or weights (W) must be used when making combined strata estimates of attributes for the population of lakes. These weights are defined, and the estimating equations are given, in Section 2.3. To emphasize the significance of the cautionary notes relating to weighting, Table 4-1 was developed as an example to compare sample results to estimated population results for pH and ANC. An examination of this table demonstrates the significance of the weighting factors in interpreting the findings of the ELS-I. The ANC values in Subregion 2D particularly exemplify the errors that can result from using unweighted sample data to infer estimated population medians.

**Table 4-1.** **Comparison of Sample Median pH and ANC to Estimated Population Medians Using Weighting Factors, Eastern Lake Survey -Phase I**

| | | pH | | ANC ($\mu eq\ L^{-1}$) | |
|---|---|---|---|---|---|
| | | Sample Median | Estimated Population Median | Sample Median | Estimated Population Median |
| SUBREGION | 1A | 6.74 | 6.71 | 116 | 112 |
| | 1B | 6.77 | 7.02 | 145 | 297 |
| | 1C | 6.78 | 6.77 | 124 | 120 |
| | 1D | 6.71 | 6.81 | 131 | 162 |
| | 1E | 6.89 | 6.91 | 138 | 148 |
| REGION | 1 | 6.80 | 6.87 | 129 | 158 |
| SUBREGION | 2A | 6.83 | 6.94 | 145 | 185 |
| | 2B | 6.61 | 7.10 | 97 | 284 |
| | 2C | 6.47 | 6.68 | 55 | 94 |
| | 2D | 6.76 | 7.39 | 134 | 802 |
| REGION | 2 | 6.74 | 7.09 | 120 | 360 |
| SUBREGION | 3A | 6.93 | 6.98 | 202 | 250 |
| | 3B | 6.52 | 6.56 | 73 | 84 |

Another example, using strata 2A1 and 2A2, illustrates the requirement that all estimates be made within strata, and that mean or other statistics involving more than one stratum be calculated with the appropriate stratum weights (Table 4-2). The correct way to estimate the total number of lakes below a reference value (in this example pH $\leq$6.0) in two strata is to determine first the total number of lakes in the sample below the reference value in each stratum ($n_c$). The next step is to determine the proportion of lakes in the sample below the reference value for each stratum ($n_c/n^{***}$:2/56 = 0.0357 and 20/46 = 0.4348). Next, multiply the proportion of sample lakes below the reference value in the stratum by the estimated number of lakes in the stratum population ($\hat{N}$), which results in $\hat{N}_c$, the estimated number of lakes in the population below the reference value. The $\Sigma\hat{N}_c$ for each stratum yields the combined stratum $\hat{N}_c$. The same answer can be obtained by multiplying $n_c$ by W for each stratum and summing the results.

The best estimate for the overall proportion of lakes in the designated population below the reference value, therefore, is 289.79/822.65 = 0.3523 (Table 4-2). If the overall proportion of lakes below the reference value were computed as 22/102 = 0.216 ($n_c/n^{***}$ for the sum of $n_c$ and $n^{***}$ for both strata), the answer would be biased. For example, there is an estimated total of 823 lakes in strata 2A1 and 2A2. Using the value of 0.3523 as $p_c$, the estimated number of lakes with pH $\leq$6.0 would be 290. Using the $p_c$ value of 0.216 (based on the combined $n_c/n^{***}$), the estimated number of lakes with pH $\leq$6.0 would be 112. Therefore, the number of lakes estimated to have pH $\leq$6.0 in both strata would be underestimated by 178 (290-112).

**Table 4-2.** **Comparison of Weights in Two Strata, 2A1 and 2A2, Eastern Lake Survey -Phase I**

| | | | | | pH ≤ 6.0 | |
|---|---|---|---|---|---|---|
| Stratum | $\hat{N}$ | $n^{***}$ | W | $n_c$ | $p_c$ | $\hat{N}_c$ |
| 2A1 | 170.13 | 56 | 3.038 | 2 | 0.0357 | 6.07 |
| 2A2 | 652.52 | 46 | 14.185 | 20 | 0.4348 | 283.72 |
| Combined | 822.65 | 102 | | 22 | 0.3523 | 289.79 |

$\hat{N}$ = estimated number of lakes within an alkalinity map class stratum.

$n^{***}$ = number of lakes from which samples were obtained.

W = weighting or expansion factor.

$n_c$ = number of lakes in the probability sample with pH ≤ 6.0, the reference value.

$p_c$ = estimated proportion of lakes in the sample or population for a stratum or combined strata, respectively, which have a pH ≤ 6.0 ($n_c/n^{***}$).

$\hat{N}_c$ = estimated number of lakes in the population which have a pH ≤ 6.0, the reference value.

A less clear issue associated with the design considerations and weighting is related to examining relationships among variables. Unweighted analyses, such as regressions or correlations, should be used with caution. For the exploratory approach used to examine a limited number of relationships for this report, we have chosen to do *unweighted* analyses. It should be noted, however, that the parameter estimates (e.g., the regression intercept or slope) do not necessarily represent those of the population. It is of interest to explore the conformity of relationships across strata and among variables of interest. Unless the relationships of interest are independent of alkalinity map class (and any factor associated with the alkalinity map class strata) these estimates can be biased, just as unweighted means or medians and total lake numbers can be.

### 4.1.2.2 Data Quality

An aspect of the analytical data quality that is useful in interpreting the data is the system decision limit (SDL, Section 3.5.2). Data below the SDL are not confidently distinguishable from blanks, but still have reported values which are meaningful in examining relationships among variables. The SDLs are summarized for measured variables in Table 4-3. The SDL should be considered when selecting reference values (Section 4.3.3.2) for comparing populations. Reference values below the SDL should not be selected if tests of significant differences are to be made. An exception is ANC with an SDL of 6.9 $\mu$eq $L^{-1}$. Because ANC can be negative, only values within the range of $-6.9$ to 6.9 are not distinguishable from blank values.

Substantial percentages of lakes in one or more regions had concentrations of extractable Al, total P, $NH_4^+$, $NO_3^-$, total Al, Fe, Mn, $SiO_2$ and DIC below the SDL (Table 4-3). These high percentages suggest that many of the waters in the ELS-I are quite dilute, as expected from the design of the Survey. Of the primary variables, a large percentage of lakes occurred below the SDL only for extractable Al, which had an SDL of 8 $\mu$g $L^{-1}$. However, as with many of the ELS-I variables, the high concentrations of extractable aluminum are of primary interest. For extractable aluminum, the SDL is well below the concentration expected to affect fish, for example (Section 5.2.4).

## 4.2 Description of the Target Population

### *4.2.1 Number of Lakes Sampled*

A total of 2681 regular (probability sample) lakes were selected from the map population. Of those, 805 were classified as non-target by examination of large-scale maps, 151 were classified as non-target

**Table 4-3. Data Quality Summary, Eastern Lake Survey -Phase I**

| Variable | System Decision Limit[a] (SDL) | Overall Within Batch Precision[b] (RMS of %RSD) | Estimated Percent of Lakes < SDL, by Region | | | | Other Known Limitations on Data Interpretation |
|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3A | 3B | |
| PRIMARY: | | | | | | | |
| pH (closed) | NA[c] | 0.04[d] | NA | NA | NA | NA | None |
| ANC | 6.9 $\mu$eq L$^{-1}$[e] | 10 | 3.5 | 1.6 | 0 | 4.0 | None |
| Sulfate | 1.9 $\mu$eq L$^{-1}$ | 6.5 | 0 | 0 | 0 | 0 | None |
| Calcium | 1.5 $\mu$eq L$^{-1}$ | 2.3 | 0 | 0 | 0 | 0 | None |
| Al, ext. | 8 $\mu$g L$^{-1}$ | 11 | 57.9 | 61.8 | 98.3 | 59.9 | Possible loss of Al in filtration. |
| DOC | 0.4 mg L$^{-1}$ | 12[f] | 0.3 | 0.3 | 0 | 3.1 | None |
| SECONDARY: | | | | | | | |
| Magnesium | 0.7 $\mu$eq L$^{-1}$ | 2.3 | 0 | 0 | 0 | 0 | None |
| Sodium | 1.2 $\mu$eq L$^{-1}$ | 4.3 | 0 | 0 | 0 | 0 | None |
| Potassium | 0.4 $\mu$eq L$^{-1}$ | 3.7 | 0.1 | 0 | 0 | 1.9 | None |
| Ammonium | 2.1 $\mu$eq L$^{-1}$ | NC[g] | 67.8 | 53.4 | 46.6 | 61.1 | Slight negative bias in two subregions. |
| Nitrate | 6.3 $\mu$eq L$^{-1}$ | 60 | 89.2 | 90.5 | 69.6 | 80.7 | Contamination of filtered aliquots required substitution using unfiltered aliquots with long holding times—some degradation occurred; slight negative bias. |
| Chloride | 2.3 $\mu$eq L$^{-1}$ | 17 | 0 | 0.2 | 0 | 0 | Unknown source of variability. |
| Fluoride | 0.3 $\mu$eq L$^{-1}$ | 8.9 | 0.4 | 0 | 1.7 | 0 | None |
| Al, total | 30 $\mu$g L$^{-1}$ | 24 | 27.4 | 58.1 | 19.0 | 25.9 | Slight Al contamination likely. |
| Iron | 22 $\mu$g L$^{-1}$ | 10 | 26.2 | 35.3 | 18.0 | 57.8 | None |
| Manganese | 11 $\mu$g L$^{-1}$ | 11 | 47.0 | 76.3 | 22.5 | 70.0 | None |
| Silica | 0.11 mg L$^{-1}$ | 2.7 | 4.2 | 9.7 | 0 | 27.4 | Slight negative bias. |
| P, total | 8 $\mu$g L$^{-1}$ | 9.7 | 43.8 | 15.8 | 53.6 | 20.4 | None |
| Conductance | 1.3 $\mu$S cm$^{-1}$ | 1.9 | 0 | 0 | 0 | 0 | None |
| DIC (open) | 0.42 mg L$^{-1}$ | 3.7 | 3.4 | 1.6 | 0 | 25.6 | None |
| Color | NA | 22 | NA | NA | NA | NA | Color in Subregion 3A not related to DOC. |
| Turbidity | NA | 19 | NA | NA | NA | NA | None |

[a] Non-parametric.
[b] Precision based on field duplicate pairs; precision computed for values above the quantitation limit.
[c] Not applicable (NA).
[d] Precision of pH expressed in pH units; all other variables expressed in %RSD.
[e] Percent of population computed for $-\text{SDL} < x < \text{SDL}$.
[f] For DOC >5 mg L$^{-1}$.
[g] Not computed (NC); all values below the quantitation limit.

when visited, and 113 were not visited (Section 2.2.4). Data from water samples collected from 1612 lakes were subsequently considered for use in making population estimates. Twenty of these lakes were separated from the remaining lakes in the analyses because of their large size (Section 4.2.2).

Of the 199 special interest lakes selected (Section 2.2.5), 186 were sampled. The data collected from special interest lakes are presented in Volumes II and III, but are not discussed in this report. Because these lakes were not part of the random selection process, weighting factors do not apply in this case (Section 4.1.2), and their representativeness with respect to the chemical characteristics of the lake populations as a whole is uncertain (Section 4.9).

### *4.2.2 Treatment of Large, Shallow and Thermally-Stratified Lakes*

Preliminary data analysis revealed that cumulative areal distributions, G(x), were affected by 20 exceptionally large (>2000 ha) lakes. These lakes had little effect on the cumulative frequency distributions, F(x), but greatly influenced the precision of G(x) (Table 4-4). For this reason, this subpopulation of lakes was excluded from this report and only those lakes ≤2000 ha (1592) are included in the analyses. It is estimated that there are 197 such large lakes in the study regions (61 in Region 1, 73 in Region 2, and 63 in Subregions 3A and 3B). These large lakes were not eliminated from the target population but rather, through their exclusion in the analyses, define a new subpopulation of interest. Estimates of numbers and characteristics of subpopulations of lakes >2000 ha are available, but precision is poor.

An objective of sampling lakes in the fall was to obtain one sample at a standard depth (1.5 m) that would best represent the entire lake chemistry. Of the 1612 probability sample lakes, 17.4 percent were sampled at a depth less than the originally prescribed depth of 1.5 m. This adjustment to the protocol for shallow lakes was required to minimize contamination of the sample from sediment.

Of the 1612 probability sample lakes sampled, three percent were weakly stratified and two percent strongly stratified (Section 2.6.2). Because hypolimnetic waters may contain higher concentrations of ANC, the surface waters of stratified lakes could have exhibited somewhat higher ANC values following mixing than were measured while the lakes were stratified. Thus, the question arose as to how representative of the entire water mass a single sample might be.

The possible bias introduced from including stratified and shallow lakes collectively in the analyses was a concern. However, because little difference was observed between population proportions for ANC based on including or excluding stratified or shallow lakes (Section 4.5.1.6), population estimates for this report are based on all lakes sampled for the subpopulation of lakes restricted by size (all lakes in the target population ≤2000 ha).

### *4.2.3 Target Population and Population Estimates*

Table 4-5 provides the basic structural computations for the sample and target populations dis-

**Table 4-4.** **Subregional and Regional Summaries of Estimated Target Population Size ($\hat{N}$), Estimated Target Population Area ($\hat{A}$), and the Standard Errors (SE) of These Estimates, Eastern Lake Survey -Phase I**

| | | All Lakes* | | | | Lakes ≤2000 ha** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $\hat{N}$ | SE($\hat{N}$) | $\hat{A}$ | SE($\hat{A}$) | $\hat{N}_s$ | SE($\hat{N}_s$) | $\hat{A}_s$ | SE($\hat{A}_s$) |
| SUBREGION | 1A | 1290 | 47.6 | 118777 | 22186 | 1290 | 47.6 | 118777 | 22186 |
| | 1B | 1506 | 90.9 | 478659 | 443078 | 1479 | 92.9 | 26872 | 2913 |
| | 1C | 1494 | 57.0 | 101578 | 29948 | 1483 | 57.5 | 72412 | 12013 |
| | 1D | 1325 | 93.6 | 95940 | 54885 | 1318 | 93.7 | 36403 | 4381 |
| | 1E | 1542 | 65.7 | 298636 | 98546 | 1526 | 66.0 | 173400 | 25725 |
| REGION | 1 | 7157 | 163.9 | 1093589 | 458727 | 7096 | 165.3 | 427865 | 36414 |
| SUBREGION | 2A | 1499 | 72.4 | 1484385 | 1214881 | 1457 | 74.2 | 142981 | 37582 |
| | 2B | 1050 | 72.5 | 34025 | 10854 | 1050 | 72.5 | 34025 | 10854 |
| | 2C | 1511 | 45.7 | 256444 | 107928 | 1480 | 48.8 | 97556 | 21357 |
| | 2D | 4515 | 293.9 | 226896 | 58202 | 4515 | 293.9 | 226896 | 58202 |
| REGION | 2 | 8575 | 314.6 | 2001749 | 1221102 | 8502 | 315.5 | 501458 | 73307 |
| SUBREGION | 3A | 286 | 20.7 | 344465 | 138586 | 258 | 20.5 | 24272 | 4795 |
| | 3B | 2138 | 214.5 | 312936 | 232528 | 2098 | 212.6 | 66169 | 10158 |

*Including lakes >2000 ha.

**Subscript s denotes a subpopulation, in this case those lakes in the target population ≤2000 ha.

**Table 4-5.** Description of Sample and Target Population (Stratum Specific), Eastern Lake Survey -Phase I

| STR | N* | n* | n*** | W | Ñ | SE(Ñ) | Å | SE(Å) |
|---|---|---|---|---|---|---|---|---|
| 1A1 | 711 | 75 | 57 | 9.633 | 549.08 | 33.08 | 78094 | 20460 |
| 1A2 | 542 | 65 | 51 | 8.338 | 425.24 | 26.13 | 21460 | 5690 |
| 1A3 | 431 | 68 | 47 | 6.719 | 315.79 | 22.14 | 19223 | 6420 |
| 1B1 | 208 | 70 | 49 | 3.192 | 156.41 | 9.29 | 3851 | 544 |
| 1B2 | 96 | 70 | 48 | 1.477 | 70.90 | 3.00 | 2046 | 233 |
| 1B3 | 1682 | 68 | 47 | 27.209 | 1278.82 | 90.37 | 472762 | 443077 |
| 1C1 | 631 | 88 | 63 | 7.822 | 492.79 | 27.31 | 26943 | 9848 |
| 1C2 | 752 | 70 | 54 | 10.743 | 580.12 | 36.20 | 53804 | 27942 |
| 1C3 | 650 | 74 | 47 | 8.953 | 420.79 | 34.59 | 20831 | 4376 |
| 1D1 | 443 | 70 | 47 | 6.572 | 308.88 | 23.00 | 67439 | 54729 |
| 1D2 | 656 | 95 | 43 | 6.905 | 296.92 | 31.14 | 8977 | 1695 |
| 1D3 | 1568 | 93 | 37 | 19.426 | 718.76 | 85.22 | 19523 | 3784 |
| 1E1 | 1038 | 130 | 89 | 8.070 | 718.23 | 39.71 | 89853 | 26873 |
| 1E2 | 606 | 74 | 48 | 8.344 | 400.51 | 31.80 | 138490 | 93036 |
| 1E3 | 744 | 72 | 41 | 10.333 | 423.65 | 41.55 | 70292 | 18259 |
| 2A1 | 176 | 60 | 56 | 3.038 | 170.13 | 3.43 | 17419 | 3382 |
| 2A2 | 778 | 62 | 46 | 14.185 | 652.51 | 37.60 | 105222 | 55019 |
| 2A3 | 1178 | 85 | 48 | 14.098 | 676.70 | 61.79 | 1361744 | 1213630 |
| 2B1 | 118 | 74 | 41 | 1.878 | 77.00 | 4.89 | 893 | 90 |
| 2B2 | 250 | 100 | 57 | 2.579 | 147.00 | 9.83 | 2776 | 500 |
| 2B3 | 1330 | 80 | 48 | 17.208 | 825.98 | 71.69 | 30357 | 10842 |
| 2C1 | 464 | 60 | 50 | 8.340 | 417.00 | 17.77 | 8044 | 1472 |
| 2C2 | 348 | 60 | 56 | 6.007 | 336.39 | 7.56 | 10432 | 1382 |
| 2C3 | 895 | 60 | 49 | 15.459 | 757.49 | 41.38 | 237968 | 107910 |
| 2D1 | 97 | 90 | 40 | 1.536 | 61.44 | 3.50 | 1071 | 94 |
| 2D2 | 699 | 85 | 53 | 9.251 | 490.30 | 34.99 | 9027 | 2103 |
| 2D3 | 5351 | 70 | 48 | 82.558 | 3962.78 | 291.82 | 216797 | 58164 |
| 3A1 | 19 | 19 | 11 | 1.071 | 11.78 | 0.58 | 874 | 96 |
| 3A2 | 76 | 60 | 47 | 1.343 | 63.12 | 1.93 | 24432 | 3914 |
| 3A3 | 443 | 100 | 44 | 4.792 | 210.85 | 20.58 | 310159 | 138531 |
| 3B1 | 1608 | 140 | 52 | 13.127 | 682.60 | 69.30 | 21763 | 3917 |
| 3B2 | 113 | 113 | 62 | 1.000 | 62.00 | 0.00 | 18705 | 0 |
| 3B3 | 6332 | 181 | 36 | 38.705 | 1393.38 | 203.05 | 272468 | 232495 |

STR = Stratum
N* = Frame population
n* = Number of lakes in the probability sample
n*** = Number of lakes sampled
W = Expansion factor
Ñ = Estimated target population size
SE(Ñ) = Standard error of Ñ
Å = Estimated area of target population
SE(Å) = Standard error of Å

cussed in this report, by strata. All estimates are made with the equations in Section 2.3.2. The weights provided in Table 4-5 are appropriate for any weighted analyses that might be necessary (Section 4.1.2.1).

## 4.3 Descriptive Statistics and Cumulative Distributions

The primary objectives of the ELS-I were to characterize the chemistry of lakes in potentially sensitive regions of the United States, to estimate the numbers of low ANC and low pH lakes, to identify where those lakes are, and to describe their characteristics. The Survey addresses these objectives by its stratified design which permits description of the populations of lakes in each of the 33 strata, representing the three alkalinity map classes within each of the 11 chosen subregions. These strata represent the basic analytic units, but as noted earlier, analyses may also be performed on any combinations of strata that have meaning to the investigator (Section 2.2.1) within regions, subregions, or subpopulations (for example, lakes ≤2000 ha).

### *4.3.1 Population Distributions*

Each population to be described was summarized on a single page of output for each variable. The cumulative distributions, F(x) and G(x), supplemented by descriptive statistics, were chosen for this purpose and serve as the primary data outputs. Figures 4-1 to 4-8 for ANC and field laboratory pH are examples. Volume II includes these outputs and those for other variables and subpopulations. Tables of summary statistics are generated from these outputs. Direct inspection of the differences among the elements or strata of the design structure can be made by using a combination of the distribution plots and tabular information provided on these data outputs.

By presenting the data as cumulative distributions, the utility and flexibility of ELS-I are enhanced. Specifically, low pH or low ANC, for example, are not unequivocally or universally defined. Therefore, several reference values for each of the primary variables were chosen, primarily to facilitate comparisons among strata, subregions, regions, or subpopulations. However, the strength of the designed population description output, as well as of the Survey design itself, is that any reference value can be evaluated, providing flexibility in interpretation of the output. As the understanding of acidification processes improves, the reference values can be changed, ensuring the utility of the ELS-I data base in the future. The considerations noted in Section 4.1.2.2, however, are important in selecting additional reference values and Section 4.3.2 provides examples of the interpretive flexibility in using the outputs.

### *4.3.2 Definitions of the Descriptive Statistics: Interpretation of F(x) and G(x) Data Output*

Each population description (Figures 4-1 through 4-8) is identified by the variable (chemical parameter) and by the subset of lakes constituting the population being examined. A subset may represent all lakes in the Survey unit, as for example, a single stratum (1A1), a subregion (1A), a region (1), or a subpopulation.

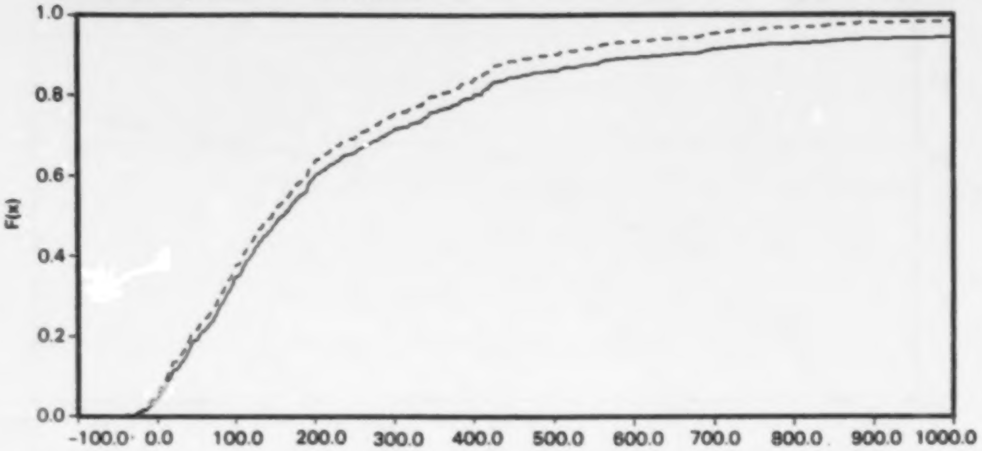
**Figure 4-1.** F(x) and G(x) distributions of ANC ($\mu$eq L$^{-1}$) for the target population of lakes ($\leq$2000 ha) sampled in Region 1 (Northeast), Eastern Lake Survey-Phase I.

16 Feb. 1986

Region 1
Subregion
Class

Variable: ANC as $\mu$eq L$^{-1}$ for lakes $\leq$2000 ha
$X_{c1}$: 0.0 $X_{c2}$: 50.0 $X_{c3}$: 200.0
Population Size (N): 7096 SE(N): 165.3
Lake Area (A): 427864 SE(A): 36414

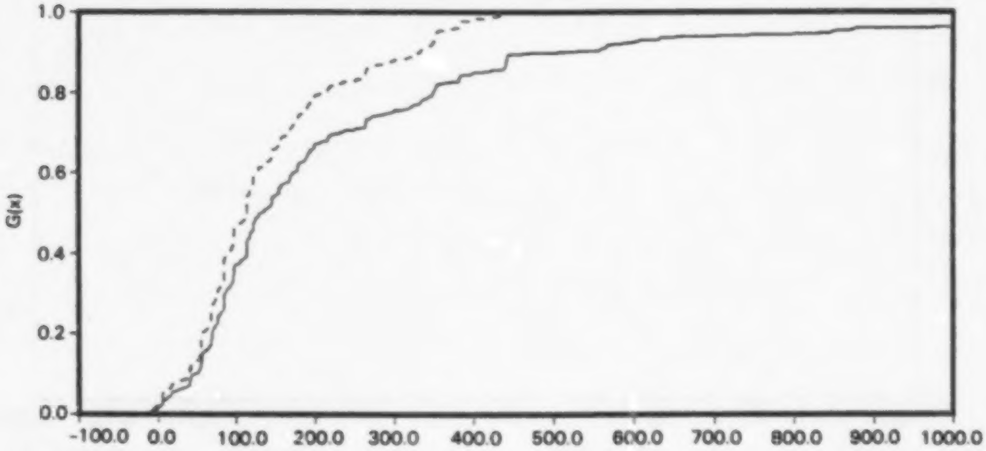
Sample Size: 763



Min: - 45.60 $Q_1$: 51.63 $Q_2$: 118.36 $Q_3$: 199.64 $Q_4$: 399.94 Max: 4046.60

Median: 158.11
Mean: 268.08
Std. Dev.: 411.69

Proportions and Numbers Below the Value of $X_c$
$p_{c1}$: 0.046 $N_{c1}$: 326 $N_{cu1}$: 422
$p_{c2}$: 0.192 $N_{c2}$: 1364 $N_{cu2}$: 1536
$p_{c3}$: 0.600 $N_{c3}$: 4258 $N_{cu3}$: 4513



Min: - 45.60 $Q_1$: 68.21 $Q_2$: 113.61 $Q_3$: 172.01 $Q_4$: 349.45 Max: 4046.60

Median: 131.94

Proportions and Numbers Below the Value of $X_c$
$g_{c1}$: 0.018 $A_{c1}$: 7756 $A_{cu1}$: 11567
$g_{c2}$: 0.102 $A_{c2}$: 43839 $A_{cu2}$: 56963
$g_{c3}$: 0.672 $A_{c3}$: 287422 $A_{cu3}$: 338943

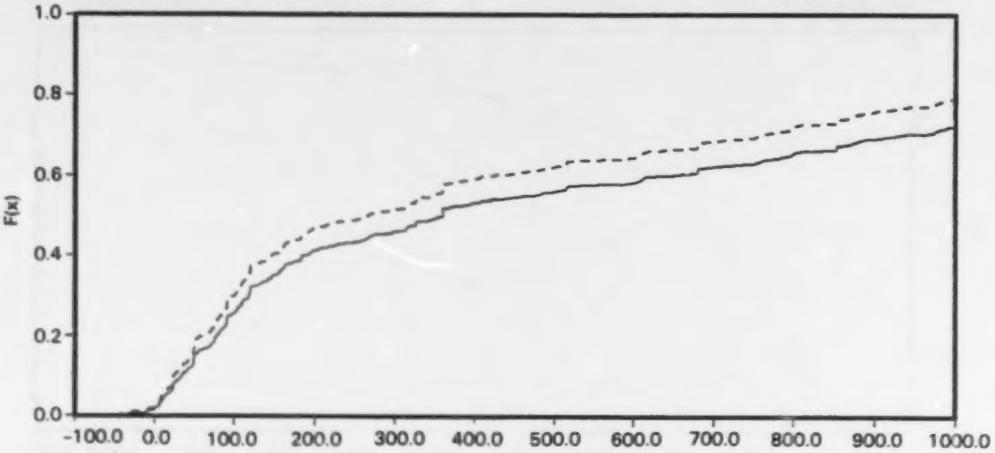
**Figure 4-2.** F(x) and G(x) distributions of ANC ($\mu$eq L$^{-1}$) for the target population of lakes (≤2000 ha) sampled in Region 2 (Upper Midwest), Eastern Lake Survey-Phase I.

16 Feb. 1986

Region 2
Subregion
Class

Variable: ANC as $\mu$eq/L for Lakes ≤2000 ha
$X_{c1}$: 0.0 $X_{c2}$: 50.0 $X_{c3}$: 200.0
Population Size (N): 8501 SE(N): 315.3
Lake Area (A): 501547 SE(A): 73306

Sample Size: 587

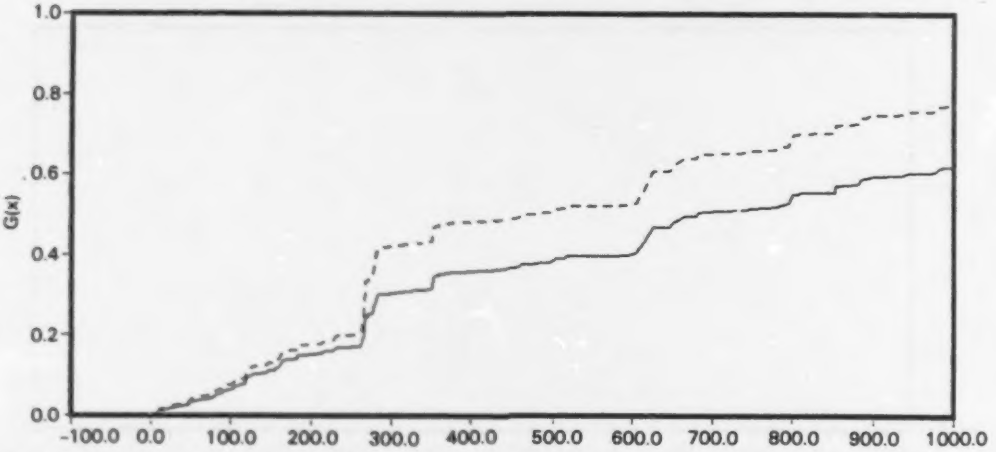


Min: − 48.60 $Q_1$: 77.82 $Q_2$: 183.94 $Q_3$: 642.97 $Q_4$: 1415.51 Max: 4002.00

Median: 359.54
Mean: 755.98
Std. Dev.: 881.14

Proportions and Numbers Below the Value of $X_c$

| | | | | | |
|---|---|---|---|---|---|
| $p_{c1}$: | 0.017 | $N_{c1}$: | 148 | $N_{cu1}$: | 209 |
| $p_{c2}$: | 0.154 | $N_{c2}$: | 1312 | $N_{cu2}$: | 1605 |
| $p_{c3}$: | 0.414 | $N_{c3}$: | 3518 | $N_{cu3}$: | 3982 |



Min: − 48.60 $Q_1$: 265.36 $Q_2$: 592.95 $Q_3$: 936.58 $Q_4$: 1860.05 Max: 4002.00

Median: 680.68

Proportions and Numbers Below the Value of $X_c$

| | | | | | |
|---|---|---|---|---|---|
| $g_{c1}$: | 0.003 | $A_{c1}$: | 1513 | $A_{cu1}$: | 2191 |
| $g_{c2}$: | 0.033 | $A_{c2}$: | 16737 | $A_{cu2}$: | 20609 |
| $g_{c3}$: | 0.152 | $A_{c3}$: | 76374 | $A_{cu3}$: | 88914 |

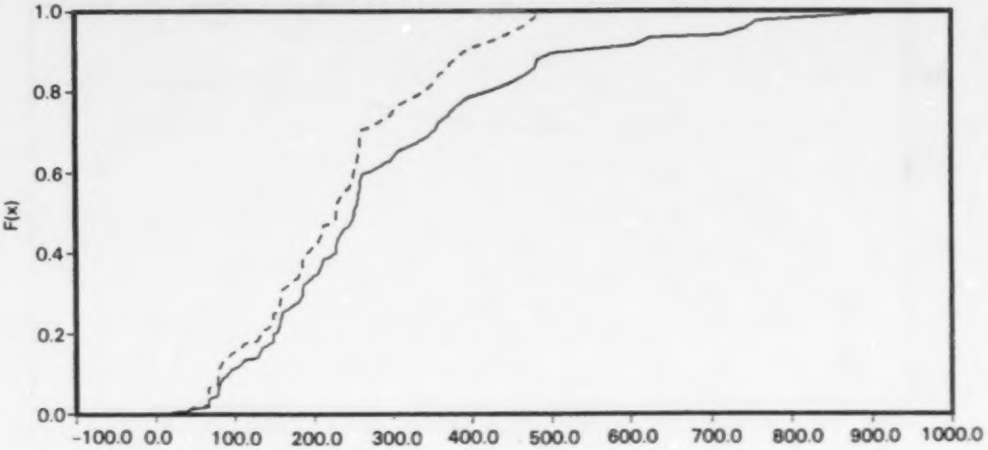
**Figure 4-3.** F(x) and G(x) distributions of ANC ($\mu$eq $L^{-1}$) for the target population of lakes (≤2000 ha) sampled in Subregion 3A (Southern Blue Ridge), Eastern Lake Survey-Phase I.

16 Feb. 1986

Region 3
Subregion A
Class

Variable: ANC as $\mu$eq/L for Lakes ≤2000 ha
$X_{c1}$: 0.0 $X_{c2}$: 50.0 $X_{c3}$: 200.0
Population Size (N): 258 SE(N): 20.5
Lake Area (A): 24272 SE(A): 4795

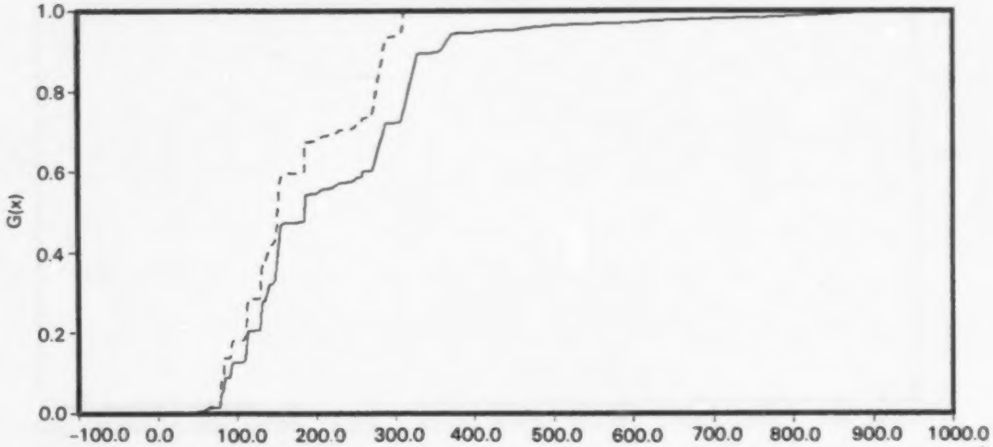
Sample Size: 94



Min: 20.20 $Q_1$: 149.15 $Q_2$: 225.74 $Q_3$: 265.80 $Q_4$: 421.36 Max: 1863.55

Median: 250.24
Mean: 303.36
Std. Dev.: 216.83

Proportions and Numbers Below the Value of $X_c$
$p_{c1}$: 0.000 $N_{c1}$: 0 $N_{cu1}$: **
$p_{c2}$: 0.014 $N_{c2}$: 3 $N_{cu2}$: 5
$p_{c3}$: 0.343 $N_{c3}$: 89 $N_{cu3}$: 108



Min: 20.20 $Q_1$: 113.16 $Q_2$: 151.44 $Q_3$: 258.09 $Q_4$: 316.83 Max: 1863.55

Median: 185.45

Proportions and Numbers Below the Value of $X_c$
$g_{c1}$: 0.000 $A_{c1}$: 0 $A_{cu1}$: **
$g_{c2}$: 0.003 $A_{c2}$: 79 $A_{cu2}$: 108
$g_{c3}$: 0.546 $A_{c3}$: 13258 $A_{cu3}$: 16436

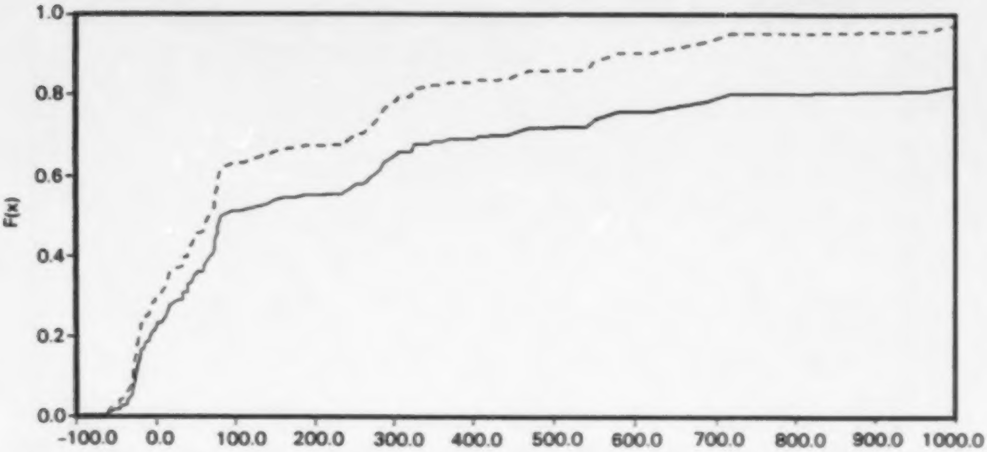
**Figure 4-4.** **F(x) and G(x) distributions of ANC ($\mu$eq L$^{-1}$) for the target population of lakes ($\leq$2000 ha) sampled in Subregion 3B (Florida), Eastern Lake Survey-Phase I.**

16 Feb. 1986

Variable: ANC as $\mu$eq/L for Lakes $\leq$2000 ha
$X_{c1}$: 0.0 $X_{c2}$: 50.0 $X_{c3}$: 200.0
Population Size (N): 2098 SE(N): 212.6
Lake Area (A): 66169 SE(A): 10158

Sample Size: 148

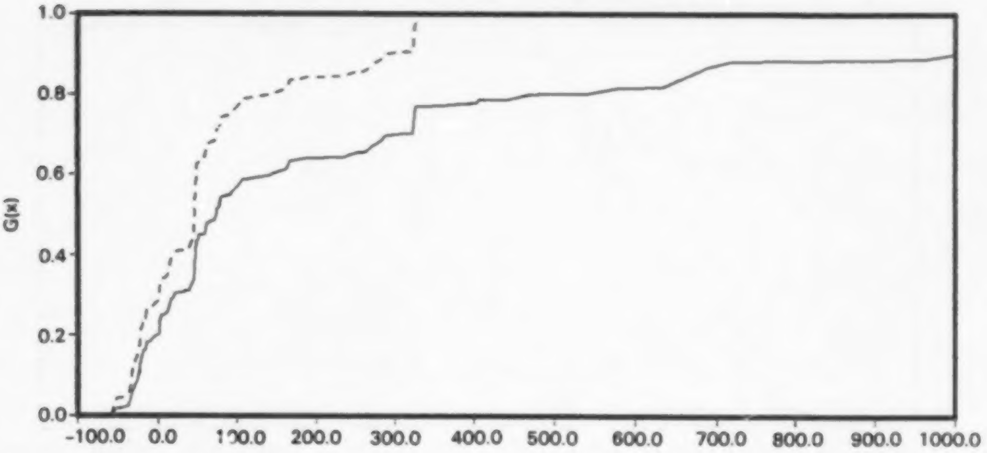
Region 3
Subregion B
Class



Min: -209.12 $Q_1$: 7.48 $Q_2$: 68.56 $Q_3$: 275.05 $Q_4$: 713.05 Max: 3639.76

Median: 83.51
Mean: 535.18
Std. Dev.: 871.42

Proportions and Numbers Below the Value of $X_c$
$p_{c1}$: 0.220 $N_{c1}$: 463 $N_{cu1}$: 615
$p_{c2}$: 0.353 $N_{c2}$: 742 $N_{cu2}$: 942
$p_{c3}$: 0.551 $N_{c3}$: 1156 $N_{cu3}$: 1413



Min: -209.12 $Q_1$: -2.06 $Q_2$: 46.72 $Q_3$: 142.97 $Q_4$: 473.83 Max: 3639.76

Median: 72.21

Proportions and Numbers Below the Value of $X_c$
$g_{c1}$: 0.202 $A_{c1}$: 13348 $A_{cu1}$: 18790
$g_{c2}$: 0.435 $A_{c2}$: 28778 $A_{cu2}$: 414020
$g_{c3}$: 0.641 $A_{c3}$: 42434 $A_{cu3}$: 55674

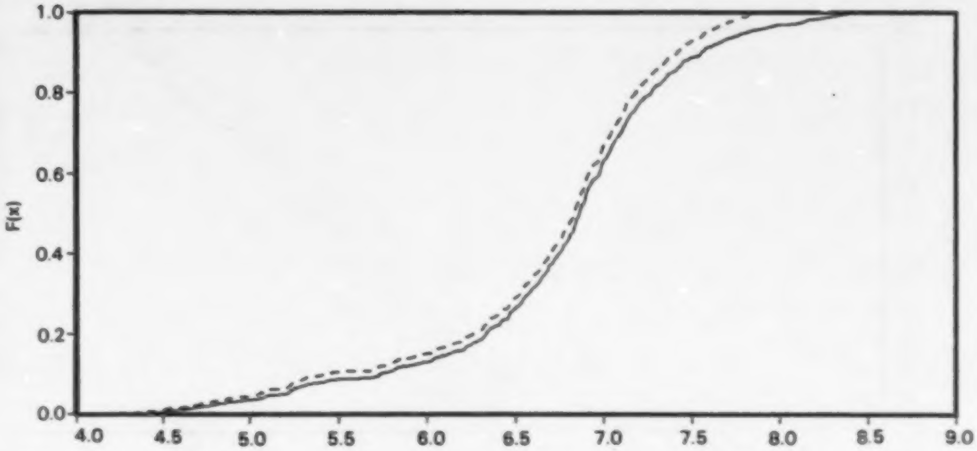
Figure 4-5. F(x) and G(x) distributions of pH (closed system) for the target population of lakes (≤2000 ha) sampled in Region 1 (Northeast), Eastern Lake Survey -Phase I.

16 Feb. 1986

Variable: pH for Lakes ≤2000 ha
$X_{c1}$: 5.0 $X_{c2}$: 5.5 $X_{c3}$: 6.0
Population Size (N): 7096 SE(N): 165.3
Lake Area (A): 427864 SE(A): 36414

Sample Size: 763

Region 1
Subregion
Class

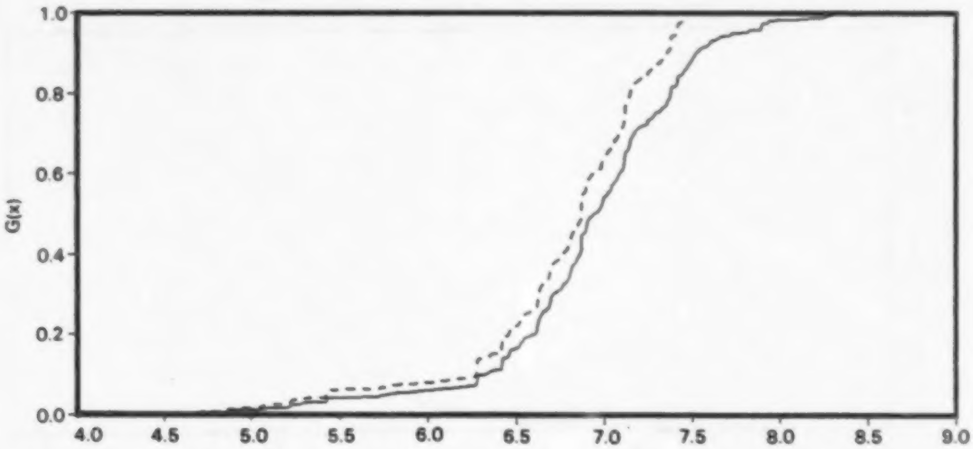


Min: 4.32 $Q_1$: 6.33 $Q_2$: 6.74 $Q_3$: 6.97 $Q_4$: 7.26 Max: 9.36

Median: 6.87
Mean: 6.76
Std. Dev.: 0.74

Proportions and Numbers Below the Value of $X_c$

| | | | | | |
|---|---|---|---|---|---|
| $p_{c1}$: | 0.034 | $N_{c1}$: | 240 | $N_{cu1}$: | 315 |
| $p_{c2}$: | 0.086 | $N_{c2}$: | 613 | $N_{cu2}$: | 737 |
| $p_{c3}$: | 0.129 | $N_{c3}$: | 916 | $N_{cu3}$: | 1056 |



Min: 4.32 $Q_1$: 6.58 $Q_2$: 7.09 $Q_3$: 7.09 $Q_4$: 7.37 Max: 9.36

Median: 6.94

Proportions and Numbers Below the Value of $X_c$

| | | | | | |
|---|---|---|---|---|---|
| $g_{c1}$: | 0.012 | $A_{c1}$: | 5059 | $A_{cu1}$: | 7570 |
| $g_{c2}$: | 0.043 | $A_{c2}$: | 18195 | $A_{cu2}$: | 26393 |
| $g_{c3}$: | 0.060 | $A_{c3}$: | 25800 | $A_{cu3}$: | 34478 |

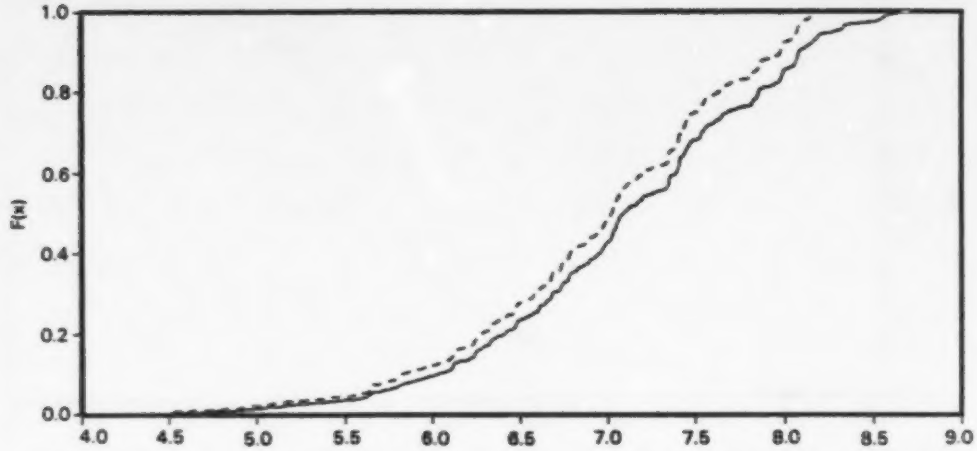
**Figure 4-6.** F(x) and G(x) distributions of pH (closed system) for the target population of lakes (≤2000 ha) sampled in Region 2 (Upper Midwest), Eastern Lake Survey-Phase I.

16 Feb. 1986

Variable: pH for Lakes ≤2000 ha
$X_{c1}$: 5.0 $X_{c2}$: 5.5 $X_{c3}$: 6.0
Population Size (N): 8501 SE(N): 315.5
Lake Area (A): 501458 SE(A): 73306

Sample Size: 587

Region 2
Subregion
Class

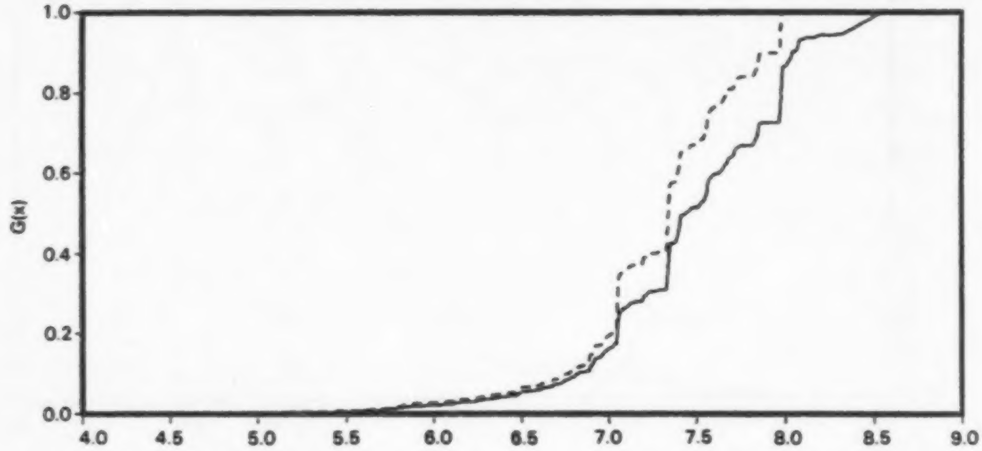


Min: 4.43 $Q_1$: 6.40 $Q_2$: 6.95 $Q_3$: 7.38 $Q_4$: 7.86 Max: 8.69

Median: 7.09
Mean: 7.09
Std. Dev.: 0.82

Proportions and Numbers Below the Value of $X_c$

| | | |
|---|---|---|
| $p_{c1}$: 0.015 | $N_{c1}$: 130 | $N_{cu1}$: 189 |
| $p_{c2}$: 0.036 | $N_{c2}$: 309 | $N_{cu2}$: 390 |
| $p_{c3}$: 0.096 | $N_{c3}$: 818 | $N_{cu3}$: 1037 |



Min: 4.43 $Q_1$: 7.04 $Q_2$: 7.35 $Q_3$: 7.63 $Q_4$: 7.98 Max: 8.69

Median: 7.44

Proportions and Numbers Below the Value of $X_c$

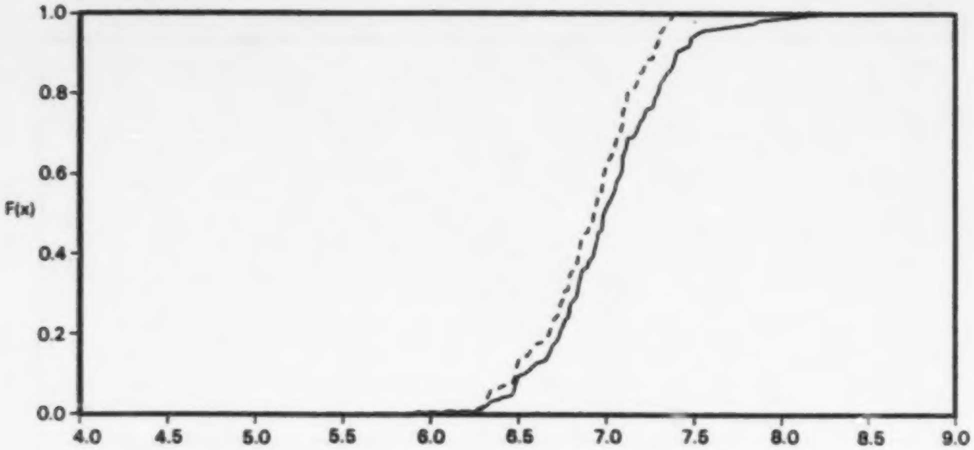
| | | |
|---|---|---|
| $g_{c1}$: 0.002 | $A_{c1}$: 1064 | $A_{cu1}$: 1553 |
| $g_{c2}$: 0.006 | $A_{c2}$: 3055 | $A_{cu2}$: 3942 |
| $g_{c3}$: 0.021 | $A_{c3}$: 10399 | $A_{cu3}$: 13686 |

Figure 4-7. F(x) and G(x) distributions of pH (closed system) for the target population of lakes (≤2000 ha) sampled in Subregion 3A (Southerm Blue Ridge), Eastern Lake Survey-Phase I.

16 Feb. 1986

Region 3
Subregion A
Class

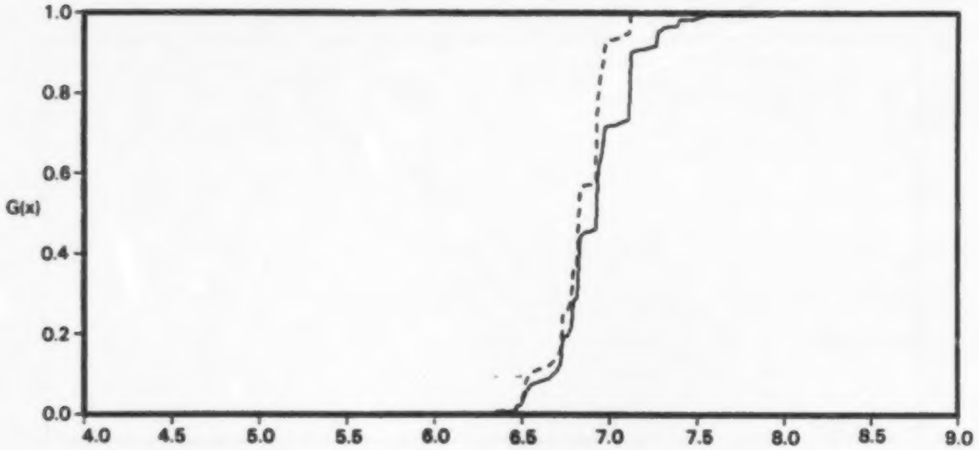
Variable: pH for Lakes ≤2000 ha
$X_{c1}$: 5.0 $X_{c2}$: 5.5 $X_{c3}$: 6.0
Population Size (N): 258 SE(N): 20.5 Sample Size: 94
Lake Area (A): 24272 SE(A): 4797



Min: 5.90 $Q_1$: 6.73 $Q_2$: 6.92 $Q_3$: 7.08 $Q_4$: 7.29 Max: 8.27

Median: 6.98
Mean: 7.01
Std. Dev.: 0.37

Proportions and Numbers Below the Value of $X_c$
$p_{c1}$: 0.000 $N_{c1}$: 0 $N_{cu1}$: **
$p_{c2}$: 0.000 $N_{c2}$: 0 $N_{cu2}$: **
$p_{c3}$: 0.004 $N_{c3}$: 1 $N_{cu3}$: 2



Min: 5.90 $Q_1$: 6.76 $Q_2$: 6.82 $Q_3$: 6.93 $Q_4$: 7.11 Max: 8.27

Median: 6.92

Proportions and Numbers Below the Value of $X_c$
$g_{c1}$: 0.000 $A_{c1}$: 0 $A_{cu1}$: **
$g_{c2}$: 0.000 $A_{c2}$: 0 $A_{cu2}$: **
$g_{c3}$: 0.001 $A_{c3}$: 13 $A_{cu3}$: 18

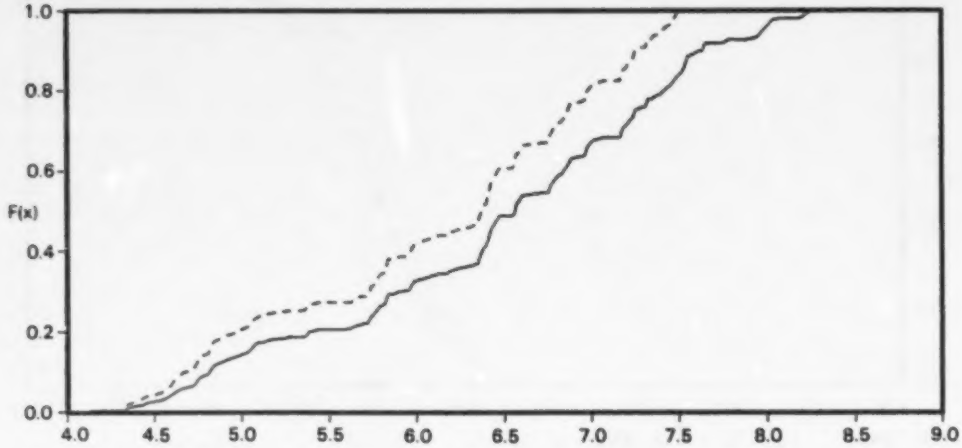
**Not Defined

**Figure 4-8.** F(x) and G(x) distributions of pH (closed system) for the target population of lakes (≤2000 ha) sampled in Subregion 3B (Florida), Eastern Lake Survey-Phase I.

Variable: pH for Lakes ≤2000 ha
$X_{c1}$: 5.0 $X_{c2}$: 5.5 $X_{c3}$: 6.0
Population Size (N): 2098 SE(N): 212.6 Sample Size: 148
Lake Area (A): 66169 SE(A): 10158

16 Feb. 1986

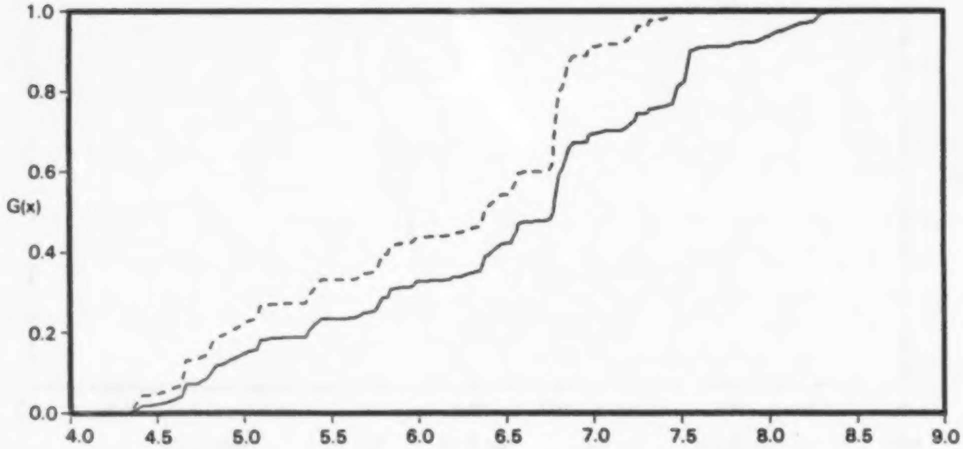
**Region 3**
**Subregion B**
**Class**



Min: 3.81 $Q_1$: 5.38 $Q_2$: 6.37 $Q_3$: 6.84 $Q_4$: 7.41 Max: 8.96

Median: 6.56
Mean: 6.45
Std. Dev.: 1.03

Proportions and Numbers Below the Value of $X_c$
$p_{c1}$: 0.124 $N_{c1}$: 259 $N_{cu1}$: 385
$p_{c2}$: 0.206 $N_{c2}$: 433 $N_{cu2}$: 574
$p_{c3}$: 0.327 $N_{c3}$: 687 $N_{cu3}$: 878



Min: 3.81 $Q_1$: 5.36 $Q_2$: 6.41 $Q_3$: 6.81 $Q_4$: 7.47 Max: 8.96

Median: 6.76

Proportions and Numbers Below the Value of $X_c$
$g_{c1}$: 0.120 $A_{c1}$: 7936 $A_{cu1}$: 12666
$g_{c2}$: 0.235 $A_{c2}$: 15553 $A_{cu2}$: 21925
$g_{c3}$: 0.327 $A_{c3}$: 21635 $A_{cu3}$: 28889

The basic population estimates, $\hat{N}$ and $\hat{A}$, and the estimated standard errors of these two estimates are presented (Figures 4-1 through 4-8) in the headings of the distribution curve output. $\hat{N}$ is defined as the estimated total number of lakes in the population being described, and $\hat{A}$ is the estimated sum of the total lake area, over all lakes in that population (denoted only as N and A on the output). The indicated sample size (equivalent to $n^{***}$, Section 2.3.2) is the number of sampled lakes in the target population being described. Identity of reference values ($X_{c1}$, $X_{c2}$, $X_{c3}$) chosen for comparative analyses completes the heading material on each page of output.

### 4.3.2.1 Distributions

The distribution curves, F(x) and G(x), are similar in interpretation, representing estimated frequency and areal distributions, respectively. For any reference value for variable X, F(x) is interpreted as the estimated proportion of lakes having a value of X $\leq$x. F(x) is calculated as the ratio of $\hat{N}_x$, the estimated number of lakes having a value of X $\leq$x, to $\hat{N}$. The upper 95 percent confidence bound on $N_x$, also scaled by dividing by $\hat{N}$, is shown as a dashed line on Figures 4-1 through 4-8. Although only a one-sided upper 95 percent confidence bound is shown, a two-sided 90 percent bound can be made by using the existing bound and one equidistant below the distribution curve. This procedure would also provide a lower 95 percent one-sided bound.

The function G(x) is interpreted similarly, as the estimated proportion of lake area in the population having a value of X $\leq$x, for any variable X. This cumulative areal curve and its confidence curve are determined analogously to the F(x) curves.

An example of interpreting these distributions is derived from Figure 4-1. At the value of ANC = 200 $\mu$eq $L^{-1}$, F(200) = 0.59 (calculated and shown on the figure as $p_{c3}$ = 0.600); the upper bound is read from the dashed line as 0.64. These values are multiplied by the estimated total number of lakes in the population, 7096, to yield 4187 (calculated and shown on the figure as $N_{c3}$ = 4258) as the estimated number of lakes in the population having ANC $\leq$200 $\mu$eq $L^{-1}$ with an upper confidence bound for that number, 4541 (calculated and shown on the figure as $N_{cu3}$ = 4513). The difference between the calculated values and those derived from the figure is due to the imprecision of obtaining the proportions (0.59 and 0.64) from the curve. The practice of reading values from the curves is suitable only for obtaining rough estimates, due to the potential error that can be introduced. Precise computation requires the use of the data base and the appropriate algorithms.

Similarly, at ANC = 200 $\mu$eq $L^{-1}$ the G(x) curve yields 0.67 (calculated and shown on the figure as $g_{c3}$ = 0.672) and 0.79, which multiplied by total lake area in the population (427,864 ha) yields 286,669 ha (calculated and shown on the figure to be $A_{c3}$ = 287,422 ha) and 338,013 ha (calculated and shown on the figure to be $A_{cu3}$ = 338,943 ha) for the estimate and upper bound for the lake area below ANC = 200 $\mu$eq $L^{-1}$. Again, estimates from the distributions should be made with caution.

Another potential complication in the interpretation of the distribution curves should be noted. Specifically, a plot of F(x) cannot be used to get confidence bounds on the number of lakes above a reference value of X. When the reference value for variable X might best be discussed in terms of the population greater than x, the plots are presented as complementary distributions, 1−F(x) and 1−G(x). These plots can be computed for any variable of interest. Examples of these descriptions are found in 4.6.1 for sulfate and, as appropriate, in Volume II.

### 4.3.2.2 Statistics

Associated with each distribution are the following descriptive statistics:

- Mean and standard deviation, appropriately weighted to reflect the estimated distribution, F(x). There are no comparable statistics for G(x).
- MIN and MAX are the minimum and maximum values of variable X observed in samples for the population or subpopulation being examined.
- The median is the estimated value of variable X such that half the number of lakes, or half the lake area, in the population are below this value.
- The quintiles ($Q_1$, $Q_2$, $Q_3$, $Q_4$, $Q_5$) are the values of X that partition the distribution into 5 equal parts (e.g., the 4th quintile is the 80th percentile; $Q_5$ is the maximum value). These values are particularly useful in comparing differences among subpopulations.
- For each of the designated reference values of variable X, denoted $X_c$, is printed the corresponding value of:

$$p_c,\ \hat{N}_c \text{ and } N_{cu}\ ,$$

or

$$g_c,\ \hat{A}_c \text{ and } A_{cu}$$

where $p_c$ = the estimated proportion of lakes,

$\hat{N}_c$ = the estimated number of lakes,

$N_{cu}$ = the upper confidence bound on number of lakes,

$g_c$ = the estimated proportion of lake area,

$\hat{A}_c$ = the estimated area of lakes, and

$A_{cu}$ = the upper confidence bound on area of lakes having the value of $X \leq X_c$ (or $\geq X_c$).

- For single strata only, an upper confidence limit also is provided for $p_c$ (Volume II).

### *4.3.3 Comparisons of Distributions*

One of the most informative ways to examine differences among population distributions is by superimposing F(x) plots. Examples of how such plots, weighted for the differences in lake population numbers within/among strata, can be interpreted are presented below for pH and ANC. With regard to pH (Figure 4-9), Subregion 1A is distinct from the other subregions in Region 1, having many more lakes in the lower tail of the distribution. In Region 2, there is considerably more variation among the subregions than in Region 1, with all subregions but 2A having substantially more variation from Region 1. Subregion 2A, however, has a very different distribution than others in Region 2, with greatly lower within-population variation. Region 3 should not be considered as a whole because the two subregions are markedly different. Subregion 3A has very little within-population variation, while the pH distribution in Subregion 3B showed considerable variation.

The plots of ANC distributions (Figure 4-10) show, as expected, similarities to the pH plots. In Region 1, a family of curves is seen for 1A-1D, with 1A shifted to the left. Acid neutralizing capacity is higher in Subregion 1B. Subregions 1A and 1B essentially form the envelope of the distributions of the two variables, pH and ANC. Subregion 1E has few lakes of low pH, but many lakes of low ANC. In Region 2, the pattern of ANC in Subregions 2A, 2B, and 2D is consistent with that of the pH curves. Many sites have low ANC in Subregion 2C. A few acidic lakes (ANC $\leq 0$ $\mu$eq $L^{-1}$) occur in Subregion 2B, but most lakes in the subregion have higher ANC than other parts of the Upper Midwest. The ANC distribution for 3B (Florida) was very similar to that for 2C (Northcentral Wisconsin). In both cases there were many low ANC systems, largely seepage lakes (Section 4.4), and then a change in the shape of the curve due to higher ANC in other lake types. A straightline increase in F(x) was observed in both pH distributions.

Other similarities in the F(x) for ANC among subregions were observed for Subregions 1E, 2A and 3A. The shape of the curve for 1A was also related, but apparently shifted as a result of more low ANC lakes.

### *4.3.4 Interpretation of Alkalinity Map Classes*

The third level of stratification in the ELS-I design (Section 2.2.1) was alkalinity map class. Comparisons among alkalinity map classes provide evidence as to the effectiveness of this level of stratification.

The maps showing the alkalinity map classes are provided in Figures 2-2 through 2-4. Because of the map scale, there will be a diversity of ANC values for lakes found within any one alkalinity map class. If the alkalinity map classes are useful as stratification factors, a random sample of lakes within a map class will yield more lakes of the designated class than any other class.

In Regions 1 and 2, the largest percentage of lakes that had ANC values $<100$ $\mu$eq $L^{-1}$ occurred in map class 1 and the lowest percentage in map class 3 (Table 4-6). Subregion 3A had few lakes (12) in map class 1 but the results were as expected. Subregion 3B had many class 1 and 3 lakes, but few class 2 lakes. However, the largest percentage of lakes with ANC $<100$ $\mu$eq $L^{-1}$ occurred in map class 1, as anticipated.

Results similar to those expected for alkalinity map class 3 were observed (Table 4-6). Alkalinity map class 2 was apparently less effective than map classes 1 and 3 as a stratification factor. The original maps were developed from data available at the time. Most of these data were not obtained in the fall nor were they obtained within the same year for all systems. Considering seasonal and yearly ANC variability, it was therefore not surprising to observe many lakes with ANC $<100$ $\mu$eq $L^{-1}$ or $>200$ $\mu$eq $L^{-1}$ within map class 2. Map class 2 was, however, an effective stratification factor in the Southern Blue Ridge. In Florida (3B) very few lakes with observed ANC from 100 to 200 $\mu$eq $L^{-1}$ occurred in map class 2; thus, there was poor agreement between the observed percentage of lakes with ANC in this range and the expected percentage based on map class 2.

In conclusion, the field data suggest that the stratification was effective, but the effectiveness varied by region and map class, and within subregional strata (not shown). This is consistent with the intended use of the alkalinity maps (i.e., they are a meaningful representation of spatial alkalinity patterns). However, even though the stratification was effective, the population of lakes in each map class within a region will not be entirely in that alkalinity class. Each map class is a mixture of alkalinity classes. For example, in Region 2, there are nearly

Figure 4-9. Comparisons among subregions of cumulative frequency distributions [F(x)] for pH (closed system), Eastern Lake Survey-Phase I.

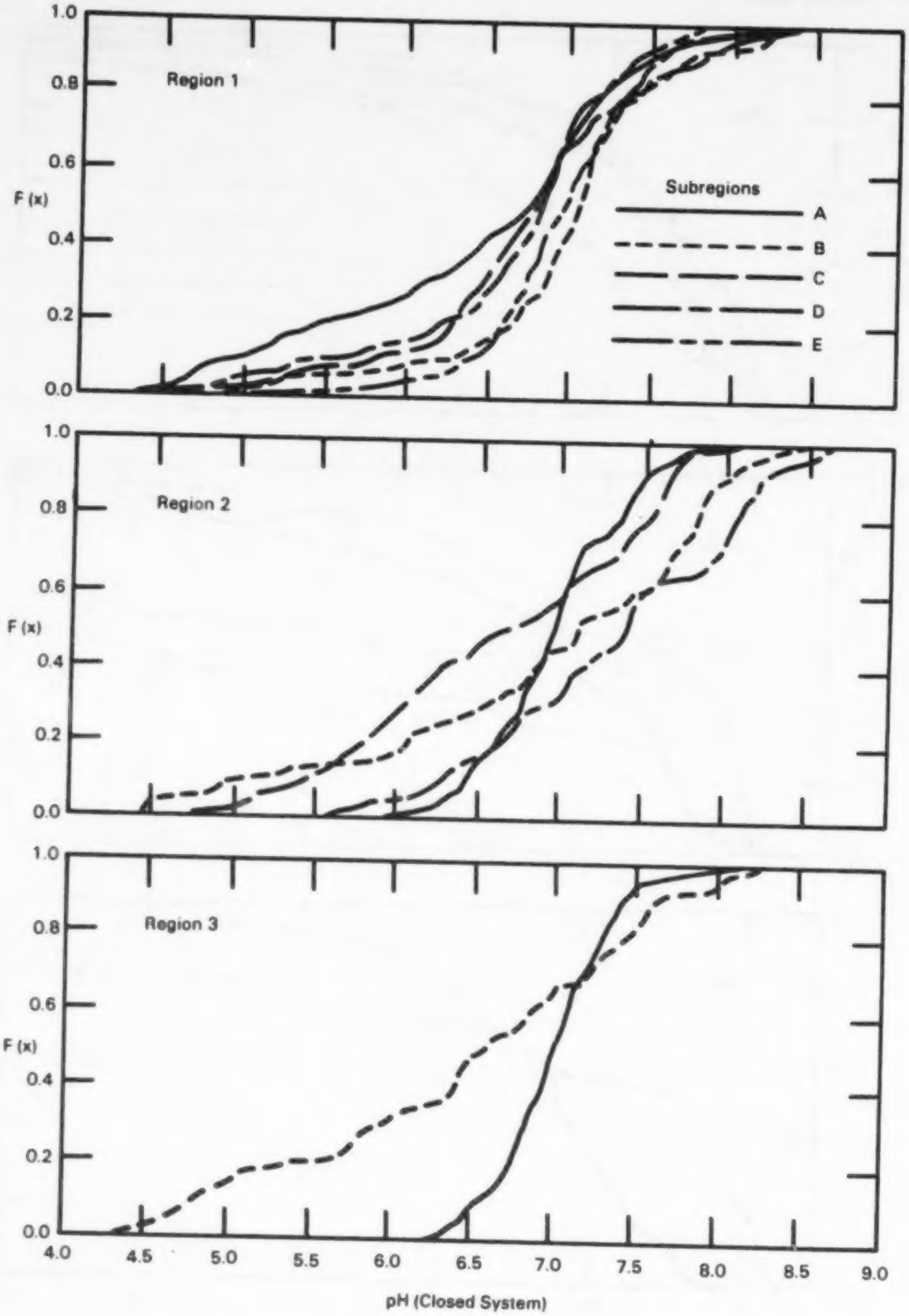


**Figure 4-10.** Comparisons among subregions of cumulative frequency distributions [F(x)] for ANC ($\mu$eq $L^{-1}$) Eastern Lake Survey-Phase I.

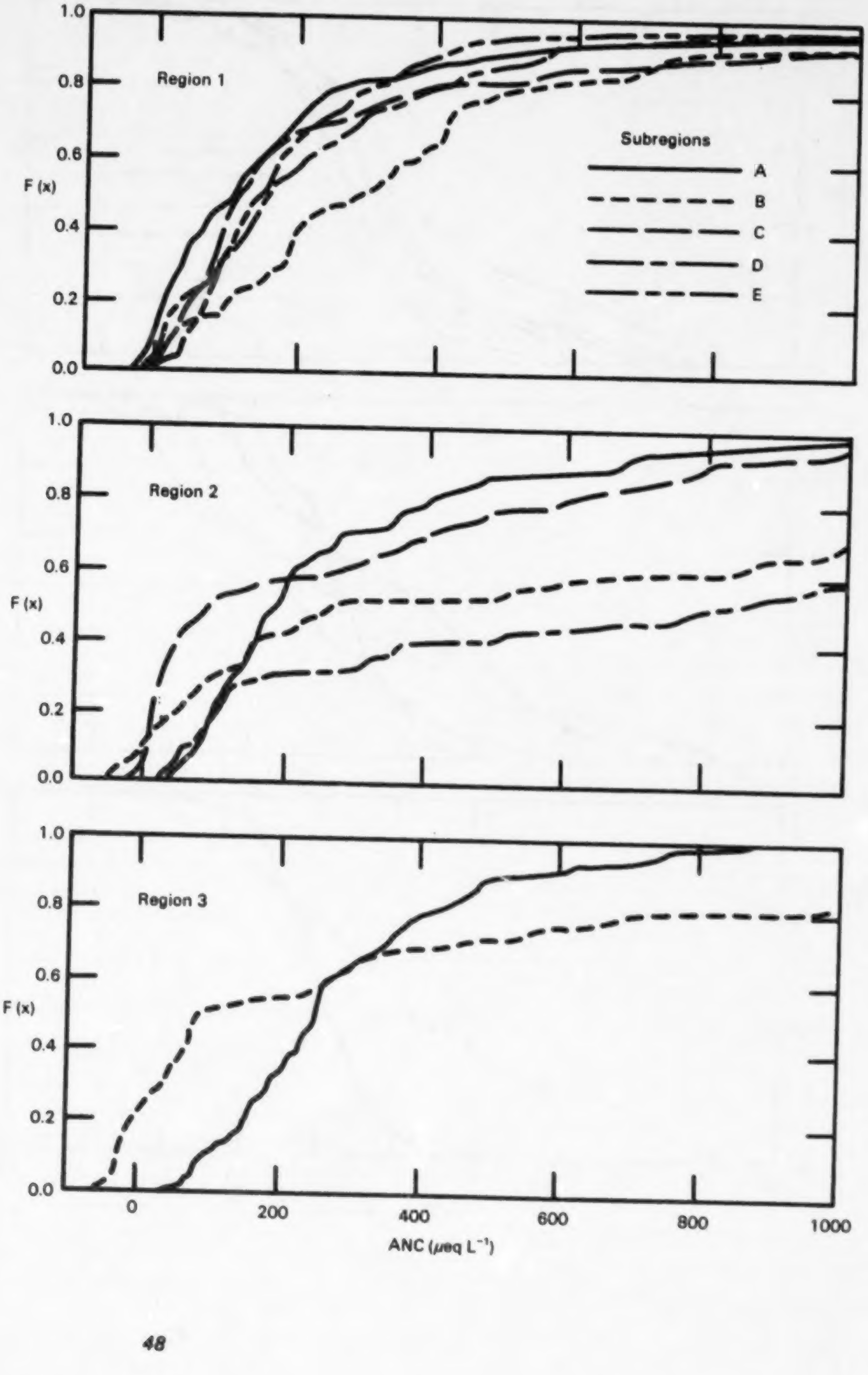


**Table 4-6.** **Composition of the Alkalinity Map Classes, in Numbers and Percentage of Lakes Having Measured ANC ($\mu eq\ L^{-1}$) in those same Classes: 1) <100, 2) 100-200, 3) >200 for Lakes ≤2000 ha, Eastern Lake Survey-Phase I[*]**

| | Estimated Percentage by Measured Class | | | Estimated Number |
|---|---|---|---|---|
| | 1 | 2 | 3 | |
| Region 1 | | | | |
| Map Class 1 | 55.1 | 33.1 | 11.8 | 2,211 |
| Map Class 2 | 46.3 | 27.4 | 26.3 | 1,755 |
| Map Class 3 | 14.4 | 18.1 | 67.5 | 3,130 |
| Region 2 | | | | |
| Map Class 1 | 73.4 | 14.8 | 11.8 | 726 |
| Map Class 2 | 40.0 | 36.9 | 23.1 | 1,598 |
| Map Class 3 | 16.2 | 10.5 | 73.3 | 6,177 |
| Subregion 3A | | | | |
| Map Class 1 | 45.4 | 27.3 | 27.3 | 12 |
| Map Class 2 | 22.7 | 47.7 | 29.6 | 59 |
| Map Class 3 | 5.1 | 15.4 | 79.5 | 187 |
| Subregion 3B | | | | |
| Map Class 1 | 73.1 | 5.8 | 21.1 | 683 |
| Map Class 2 | 52.5 | 8.2 | 39.3 | 61 |
| Map Class 3 | 40.0 | 2.9 | 57.1 | 1,354 |

*This comparison can also be made at the stratum level within subregions to examine the effectiveness of the alkalinity map class stratification. Although there is considerable variability among strata within subregions, and thus the effectiveness of stratification also varies at this scale, the above presentation suggests that within the regions as a whole the alkalinity map class stratification was appropriate.

as many observed class 1 lakes in alkalinity map class 3 as in classes 1 and 2 combined [(0.162 × 6177 = 1001) ≅ (0.734 × 726 = 533) + (0.400 × 1598 = 639)].

## 4.4 Physical Characteristics of Regional Lake Populations[3]

### *4.4.1 Northeast*

Northeastern watersheds were generally larger than those in the Upper Midwest and Florida (3B), but smaller than those in the Southern Blue Ridge (3A; Table 4-7). Maine (1E) had the largest median watershed area in the Northeast (472 ha), while the Poconos/Catskills (1B) had the smallest (169 ha). Maine (1E) had the largest median lake area (29.1 ha; the Adirondacks (1A) had the second largest (20.9 ha). Lakes in the Poconos/Catskills (1B) were uniformly small (median = 12.7 ha, fourth quintile, $Q_4$ = 22.6 ha). Site depths in the Poconos/Catskills (1B) and Southern New England (1D) were among the shallowest of all subregions (median site depth = 3.2 m and 2.9 m, respectively) (Table 4-7). Drainage lakes predominated in the Northeast (71% overall; Table 4-8); in the Poconos/Catskills (1B), reservoirs were common (42%); reservoirs were also common in Southern New England (1D; 29%), as were seepage lakes (13%). Of the northeastern (Region 1) lakes, those in the Adirondacks (1A) and the Poconos/Catskills (1B) were at the highest elevation (Table 4-7). Roads and dwellings were the predominant watershed disturbances in all subregions, although logging was also commonly observed in Maine (1E).

### *4.4.2 Upper Midwest*

Median watershed areas in all subregions of the Upper Midwest were less than those in all subregions of the Northeast except the Poconos/Catskills (1B, Table 4-7). Median watershed areas in the Upper Peninsula of Michigan (2B) and Northcentral Wisconsin (2C) were among the smallest of any of the subregions (115 and 112 ha, respectively). Lakes in the Upper Peninsula of Michigan (2B) were also among the smallest (median area = 11.1 ha) and shallowest (median depth = 2.9 m) of any subregion (Table 4-7). Drainage lakes (50%) and seepage lakes (43%) were the most common lake types in the Upper Midwest (Table 4-8). Seepage lakes were predominant in Northcentral Wisconsin (2C; 59%) and the Upper Great Lakes Area (2D; 47%), although drainage lakes were more common in the Upper Peninsula of Michigan (2B; 51%) and in Northeastern Minnesota (2A; 74%). Roads and dwellings were the predominant watershed disturbances in the Upper Midwest. Roads and dwellings were half as frequent in Northeastern Minnesota (2A) and the Upper Peninsula of Michigan (2B) as in the remainder of the region.

### *4.4.3 Southeast*

Large differences were found between the populations of lakes in the two subregions in the Southeast (Region 3). Consequently, population estimates for these subregions have not been combined to produce regional estimates.

#### 4.4.3.1 Southern Blue Ridge—Subregion 3A

Lakes in the Southern Blue Ridge had the largest median watershed area (682 ha), were among the deepest ($Q_4$ = 12.5 m), and were the smallest (median area = 10.8 ha) of any subregion (Table 4-7). Ninety percent of the lakes in Subregion 3A were reservoirs (Table 4-8). Lakes in the Southern Blue Ridge were generally higher in elevation (median = 265 m) and had a greater frequency of watershed disturbances than those in any other subregion. The primary disturbances were roads and dwellings, although logging and other land uses were also important.

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[3] All references to medians, quintiles, percentages, lake numbers, and areas are estimates of population values but are not always noted as estimates in the text. Information on upper confidence limits is provided in the tables but is not discussed in the text. The values for $p_c$ (proportions) in the tables can be converted to percentages by multiplying $p_c$ by 100.

Table 4-7. Physical Lake Characteristics: Medians (M) and First and Fourth Quintiles ($Q_1$ and $Q_4$), Eastern Lake Survey-Phase I

| | | Lake Elevation (m) | | | Watershed Area (ha) | | | Lake Area (ha) | | | Site Depth (m) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ |
| SUBREGION | 1A | 339 | 486 | 566 | 114 | 265 | 1961 | 8.4 | 20.9 | 84.7 | 2.2 | 5.6 | 10.1 |
| | 1B | 232 | 361 | 479 | 72 | 169 | 430 | 8.2 | 12.7 | 22.6 | 1.5 | 3.2 | 7.3 |
| | 1C | 150 | 295 | 408 | 111 | 353 | 1564 | 7.4 | 14.3 | 67.8 | 1.8 | 4.5 | 8.3 |
| | 1D | 34 | 171 | 601 | 65 | 237 | 558 | 7.5 | 15.0 | 44.8 | 1.2 | 2.9 | 5.9 |
| | 1E | 69 | 136 | 316 | 123 | 472 | 3187 | 8.7 | 29.1 | 140.3 | 1.8 | 4.9 | 10.6 |
| REGION | 1 | 110 | 307 | 491 | 90 | 271 | 1289 | 8.0 | 16.7 | 62.7 | 1.6 | 4.2 | 8.3 |
| SUBREGION | 2A | 426 | 458 | 534 | 69 | 201 | 1681 | 8.7 | 17.0 | 70.0 | 2.2 | 5.3 | 11.6 |
| | 2B | 224 | 267 | 451 | 46 | 115 | 659 | 5.1 | 11.1 | 22.2 | 1.0 | 2.9 | 7.6 |
| | 2C | 480 | 494 | 510 | 47 | 112 | 575 | 6.4 | 15.6 | 77.6 | 3.9 | 6.0 | 10.0 |
| | 2D | 331 | 387 | 416 | 59 | 181 | 1578 | 8.0 | 16.2 | 37.4 | 2.2 | 5.9 | 11.3 |
| REGION | 2 | 339 | 408 | 487 | 56 | 177 | 1023 | 7.6 | 14.8 | 46.1 | 2.2 | 5.6 | 10.9 |
| SUBREGION | 3A | 221 | 265 | 454 | 182 | 682 | 5836 | 5.2 | 10.8 | 64.3 | 2.3 | 4.8 | 12.5 |
| | 3B | 15 | 21 | 31 | 35 | 115 | 352 | 6.5 | 17.3 | 44.1 | 1.5 | 2.7 | 5.2 |

Table 4-8. Population Estimates of Lake Type: Number of Lakes,* Eastern Lake Survey-Phase I

| | | Reservoir | Drainage | Closed | Seepage | Estimated** Total Number of Lakes |
|---|---|---|---|---|---|---|
| SUBREGION | 1A | 100 (8) | 991 (77) | 89 (7) | 110 (8) | 1290 |
| | 1B | 622 (42) | 799 (54) | 0 (0) | 58 (4) | 1479 |
| | 1C | 70 (5) | 1206 (81) | 105 (7) | 102 (7) | 1483 |
| | 1D | 381 (29) | 690 (52) | 80 (6) | 167 (13) | 1318 |
| | 1E | 43 (3) | 1386 (91) | 56 (4) | 41 (3) | 1526 |
| REGION | 1 | 1216 (17) | 5072 (71) | 330 (5) | 478 (7) | 7096 |
| SUBREGION | 2A | 31 (2) | 1074 (74) | 119 (8) | 232 (16) | 1457 |
| | 2B | 52 (5) | 539 (51) | 64 (6) | 396 (38) | 1050 |
| | 2C | 15 (1) | 529 (36) | 60 (4) | 876 (59) | 1480 |
| | 2D | 84 (2) | 2080 (46) | 208 (5) | 2142 (47) | 4515 |
| REGION | 2 | 182 (2) | 4222 (50) | 451 (5) | 3646 (43) | 8501 |
| SUBREGION | 3A | 232 (90) | 18 (7) | 7 (3) | 0 (0) | 258 |
| | 3B | 0 (0) | 452 (21) | 265 (13) | 1380 (66) | 2098 |

*Percentages are shown in parentheses.

**May differ slightly from row total due to rounding error.

#### 4.4.3.2 Florida—Subregion 3B

Lakes in Florida (Subregion 3B) had the lowest median elevation (21 m) of any subregion. These lakes had small watersheds ($Q_4$ = 352 ha) in which roads and dwellings were commonly observed. They were among the shallowest (median site depth = 2.7 m) of any subregion (Table 4-7). Seepage lakes were most common (66%), followed by drainage lakes (21%) and closed lakes (13%). No reservoirs were sampled in Florida (Table 4-8).

## 4.5 Regional, Subregional and State Population Estimates: ANC and pH

### *4.5.1 Acid Neutralizing Capacity*

#### 4.5.1.1 Reference Values

Three reference values for ANC have been given: 0, 50, and 200 $\mu$eq $L^{-1}$. These reference values were selected for the following reasons. A sample with an ANC of 0.0 $\mu$eq $L^{-1}$ or less is acidic by definition. A reference value for ANC of 50 $\mu$eq $L^{-1}$ was chosen because lakes with this ANC value, while having some acid neutralizing capacity, may experience important decreases in ANC as a result of episodic events (i.e., snowmelt or heavy rains). A concentration of ANC $\leq$200 $\mu$eq $L^{-1}$ has been used frequently as a value separating "sensitive" lakes from other lakes (Section 5.1.3). The data shown in the tables for ANC $\leq$50 $\mu$eq $L^{-1}$ and ANC $\leq$200 $\mu$eq $L^{-1}$ are cumulative. Thus, ANC $\leq$50 $\mu$eq $L^{-1}$ includes lakes with ANC $\leq$0 $\mu$eq $L^{-1}$; ANC $\leq$200 $\mu$eq $L^{-1}$ includes lakes with ANC $\leq$0 $\mu$eq $L^{-1}$ and $\leq$50 $\mu$eq $L^{-1}$.

#### 4.5.1.2 Northeast

In the Northeast, acidic lakes (ANC $\leq$0 $\mu$eq $L^{-1}$) were concentrated in the Adirondacks, in the

Poconos, on Cape Cod, along the Rhode Island/Connecticut border, in northcentral Massachusetts/southwestern New Hampshire, and in central Maine (Figure 4-11).

Within the Northeast, the highest number (138) and percentage (11%) of acidic lakes were estimated to have occurred in the Adirondacks (1A; Table 4-9). The largest area (2937 ha) and highest areal percentage (11%) of acidic lakes were in the Poconos/Catskills (1B). Maine (1E) was estimated to have few acidic lakes. The highest number (459) and percentage (36%) and the greatest area (14,504 ha) of lakes with ANC $\leq 50\ \mu eq\ L^{-1}$ also was estimated for the Adirondacks (1A; Table 4-10). The highest areal percentage (21%) of lakes with ANC $\leq 50\ \mu eq\ L^{-1}$ occurred in the Poconos/Catskills (1B). Maine (1E) was estimated to have the fewest (165) lakes with ANC $\leq 50\ \mu eq\ L^{-1}$, but these represented a large area (11,428 ha). In Region 1, except in the Poconos/Catskills (1B), the majority of lakes was estimated to have ANC $\leq 200\ \mu eq\ L^{-1}$ (Table 4-11). Sixty-seven percent of the lake area in the Northeast had ANC $\leq 200\ \mu eq\ L^{-1}$.

### 4.5.1.3 Upper Midwest

Within the Upper Midwest, most of the acidic lakes occurred in the Upper Peninsula of Michigan (2B; 102) and in Northcentral Wisconsin (2C, 45; Table 4-9). No acidic lakes were sampled in Northeastern Minnesota (2A) or in the Upper Great Lakes Area (2D). In the Upper Midwest, lakes with ANC $\leq 50\ \mu eq\ L^{-1}$ were located in Northcentral Wisconsin, the Upper Peninsula of Michigan (especially on the Keweenaw Peninsula and the area near Whitefish Point), and in northwestern Wisconsin (Figure 4-12). The highest number (612), largest area (9,167 ha), and highest areal percentage (9%) of lakes with ANC $\leq 50\ \mu eq\ L^{-1}$ were estimated for Northcentral Wisconsin (2C; Table 4-10). In Northeastern Minnesota (2A) and Northcentral Wiscon-

Figure 4-11. Classes of ANC ($\mu eq\ L^{-1}$) in lakes sampled in Region 1 (Northeast), Eastern Lake Survey -Phase I. (Symbols appearing offshore from Subregion 1E designate lakes sampled on islands.)

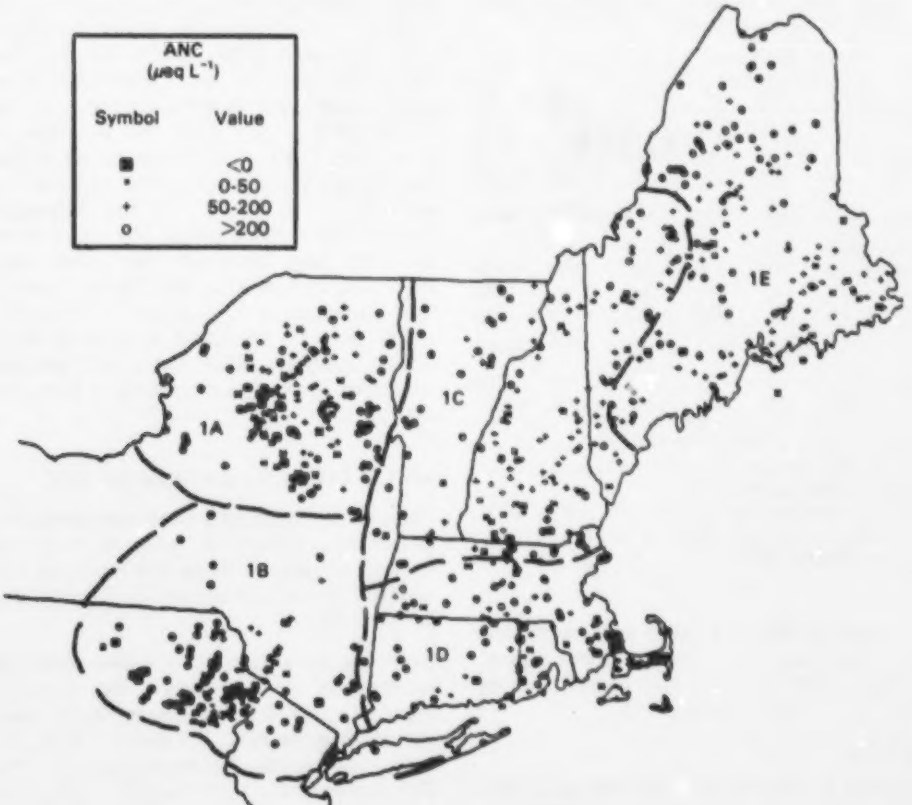


**Table 4-9. Population Estimates of Lakes with ANC ≤ 0 μeq L$^{-1}$, Eastern Lake Survey -Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.107 | 138 | 190 | 0.017 | 2056 | 3078 |
| | 1B | 0.053 | 78 | 141 | 0.109 | 2937 | 5888 |
| | 1C | 0.024 | 35 | 63 | 0.016 | 1152 | 2664 |
| | 1D | 0.050 | 66 | 107 | 0.042 | 1516 | 3084 |
| | 1E | 0.005 | 8 | 21 | 0.001 | 95 | 242 |
| REGION | 1 | 0.046 | 326 | 422 | 0.018 | 7756 | 11567 |
| SUBREGION | 2A | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 2B | 0.098 | 102 | 157 | 0.024 | 829 | 1267 |
| | 2C | 0.031 | 45 | 73 | 0.007 | 684 | 1202 |
| | 2D | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| REGION | 2 | 0.017 | 148 | 209 | 0.003 | 1513 | 2191 |
| SUBREGION | 3A | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 3B | 0.220 | 463 | 615 | 0.202 | 13348 | 18790 |

$p_c$ = estimated proportion of lakes with ANC ≤ 0 μeq L$^{-1}$.
$\hat{N}_c$ = estimated number of lakes with ANC ≤ 0 μeq L$^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of lake area with ANC ≤ 0 μeq L$^{-1}$.
$\hat{A}_c$ = estimated area of lakes with ANC ≤ 0 μeq L$^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.
(-) = undefined.

**Table 4-10. Population Estimates of Lakes with ANC ≤ 50 μeq L$^{-1}$, Eastern Lake Survey -Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.356 | 459 | 541 | 0.122 | 14504 | 21856 |
| | 1B | 0.131 | 194 | 281 | 0.213 | 5719 | 8923 |
| | 1C | 0.177 | 262 | 334 | 0.090 | 6501 | 9294 |
| | 1D | 0.216 | 284 | 368 | 0.156 | 5686 | 8319 |
| | 1E | 0.108 | 165 | 220 | 0.066 | 11428 | 21083 |
| REGION | 1 | 0.192 | 1364 | 1536 | 0.102 | 43839 | 56963 |
| SUBREGION | 2A | 0.042 | 60 | 100 | 0.005 | 705 | 1101 |
| | 2B | 0.189 | 198 | 265 | 0.062 | 2099 | 2836 |
| | 2C | 0.414 | 612 | 705 | 0.094 | 9167 | 11216 |
| | 2D | 0.098 | 441 | 708 | 0.021 | 4766 | 7943 |
| REGION | 2 | 0.154 | 1312 | 1605 | 0.033 | 16737 | 20609 |
| SUBREGION | 3A | 0.014 | 4 | 5 | 0.003 | 79 | 108 |
| | 3B | 0.353 | 742 | 942 | 0.435 | 28778 | 41420 |

$p_c$ = estimated proportion of lakes with ANC ≤ 50 μeq L$^{-1}$.
$\hat{N}_c$ = estimated number of lakes with ANC ≤ 50 μeq L$^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of lake area with ANC ≤ 50 μeq L$^{-1}$.
$\hat{A}_c$ = estimated area of lakes with ANC ≤ 50 μeq L$^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.

sin (2C), the majority (57%) of lakes was estimated to have ANC ≤200 μeq L$^{-1}$, although the Upper Great Lakes Area (2D) also had a large number of lakes (1,411) in this class (Table 4-11).

### 4.5.1.4 Southeast

Of all subregions surveyed, Florida (3B) was estimated to have the highest percentage (22%) of lakes with ANC ≤0 μeq L$^{-1}$ (Table 4-9). Lakes in the Southeast with ANC ≤50 μeq L$^{-1}$ were commonly located in the highland area of the Florida Panhandle, southeast Georgia (Okefenokee Swamp), and the central peninsula of Florida (Figure 4-13). No acidic lakes were estimated for the Southern Blue Ridge (3A) (Table 4-9); the smallest number (4), least area (79 ha), and lowest numerical and areal percentages (1% and 0.3%, respectively) of lakes with ANC ≤50 μeq L$^{-1}$ of any subregion occurred here (Table 4-10). Florida (3B) was also estimated to have the most lakes with ANC ≤50 μeq L$^{-1}$ (35% or 742 lakes comprising 28,778 ha; Table 4-10). Fifty-five percent of the lakes in Florida had ANC ≤200 μeq L$^{-1}$. Similarly, 55 percent of the lake area in the Southern Blue Ridge and 64 percent of the lake area in Florida had ANC ≤200 μeq L$^{-1}$ (Table 4-11).

**Table 4-11. Population Estimates of Lakes with ANC ≤ 200 μeq L$^{-1}$, Eastern Lake Survey -Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.705 | 909 | 995 | 0.737 | 87572 | 121699 |
| | 1B | 0.387 | 572 | 719 | 0.508 | 13647 | 18060 |
| | 1C | 0.676 | 1002 | 1100 | 0.744 | 53894 | 72587 |
| | 1D | 0.573 | 755 | 882 | 0.625 | 22763 | 28688 |
| | 1E | 0.668 | 1020 | 1121 | 0.632 | 109546 | 142497 |
| REGION | 1 | 0.600 | 4258 | 4513 | 0.672 | 287422 | 338943 |
| SUBREGION | 2A | 0.570 | 830 | 938 | 0.233 | 33277 | 41006 |
| | 2B | 0.417 | 438 | 536 | 0.172 | 5842 | 7292 |
| | 2C | 0.567 | 839 | 936 | 0.145 | 14171 | 16904 |
| | 2D | 0.313 | 1411 | 1842 | 0.102 | 23083 | 32461 |
| REGION | 2 | 0.414 | 3518 | 3982 | 0.152 | 76374 | 88914 |
| SUBREGION | 3A | 0.343 | 88 | 108 | 0.546 | 13258 | 16436 |
| | 3B | 0.551 | 1156 | 1413 | 0.641 | 42434 | 55674 |

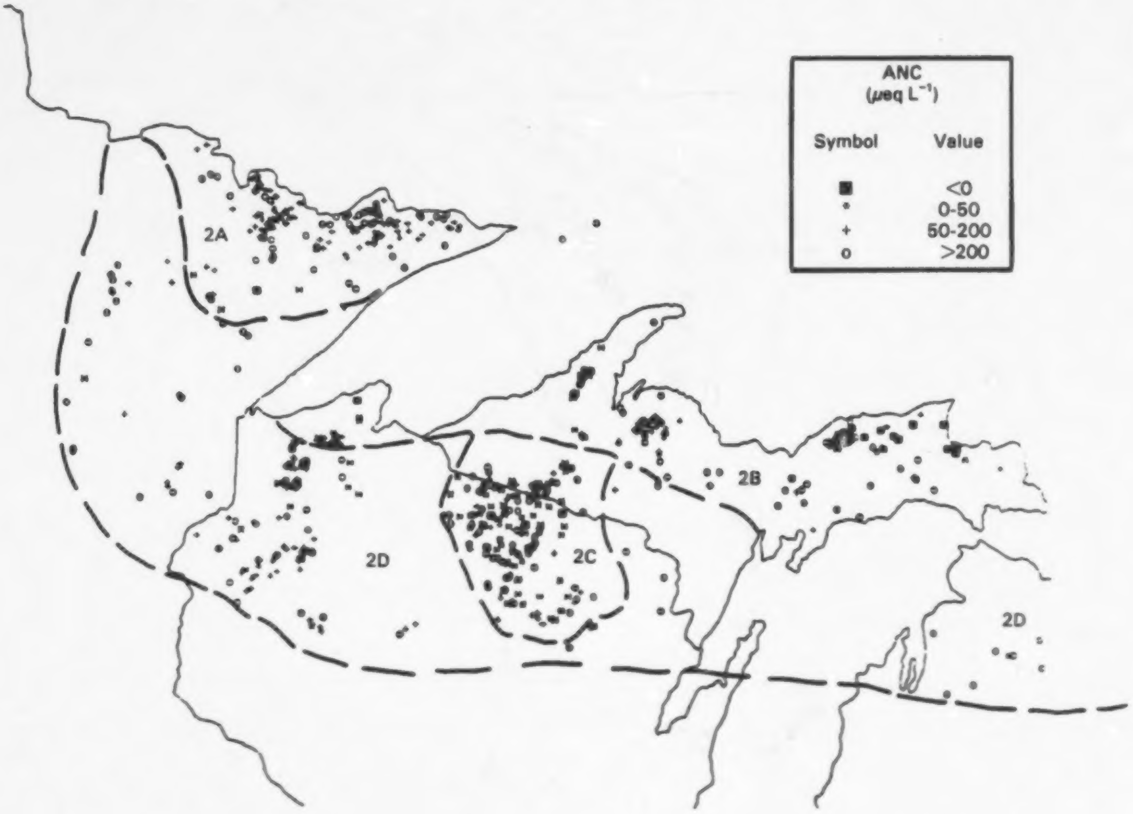
$p_c$ = estimated proportion of lakes with ANC ≤ 200 μeq L$^{-1}$.
$\hat{N}_c$ = estimated number of lakes with ANC ≤ 200 μeq L$^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of lake area with ANC ≤ 200 μeq L$^{-1}$.
$\hat{A}_c$ = estimated area of lakes with ANC ≤ 200 μeq L$^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.

### 4.5.1.5 Estimates by State for ANC

Population estimates were calculated for each state where more than 10 lakes were sampled. These estimates refer only to the portions of states covered by the ELS-I shown in Section 2.2.1 (Figures 2-1 to 2-4).

No lakes were estimated to have ANC ≤0 μeq L$^{-1}$ in Minnesota, North Carolina, South Carolina or Vermont (Table 4-12). Twenty or fewer lakes were estimated to have ANC ≤0 μeq L$^{-1}$ in Georgia, Maine, New Hampshire, Pennsylvania and Rhode Island. The highest numbers of acidic lakes were estimated for Michigan (107), New York (168) and Florida (453).

Figure 4-12. Classes of ANC ($\mu$eq $L^{-1}$) in lakes sampled in Region 2 (Upper Midwest), Eastern Lake Survey - Phase I. (Symbols appearing offshore from Subregion 2A designate lakes sampled on islands.)



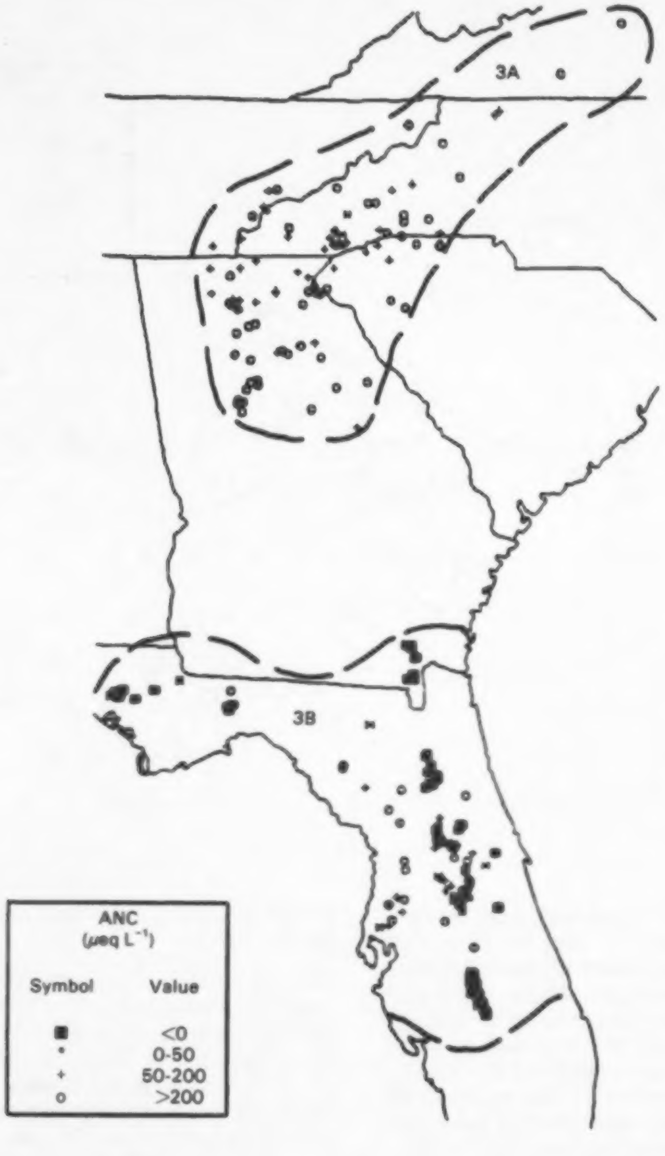
Within the Northeast, the largest estimated number of lakes with ANC $\leq 0$ $\mu$eq $L^{-1}$ was for New York (168), followed by Massachusetts (52) and Connecticut (47). All other northeastern states were estimated to have 20 or fewer lakes with ANC $\leq 0$ $\mu$eq $L^{-1}$. In the Upper Midwest, the estimate of acidic lakes for Michigan (107) exceeded the estimates for Wisconsin (41) and Minnesota (0). The states in the Southern Blue Ridge were estimated to have very few or no acidic lakes, while the highest of all state estimates of acidic lakes was for Florida (453).

### 4.5.1.6 Stratified and Shallow Lakes

Of the estimated population of the lakes $\leq 2000$ ha, 3 percent were weakly stratified and 2 percent were strongly stratified (Section 2.6.2). In addition, some lakes were $\leq 3$ m in depth and were sampled at 0.5 m instead of 1.5 m. Data from these stratified and shallow lakes were included in population estimates with data from nonstratified lakes sampled at 1.5 m, because including them had little, if any, influence on the estimated population characteristics for ANC.

Table 4-13 shows population estimates by subregion for lakes $\leq 200$ $\mu$eq $L^{-1}$ ANC based on several subpopulations of lakes. Listed are nonstratified lakes sampled at 1.5 m (a), all nonstratified lakes (b), all stratified lakes (c), lakes sampled at 1.5 m (d), lakes sampled at 0.5 m (e), and all lakes (f). The estimates for ANC $\leq 200$ $\mu$eq $L^{-1}$ are given as an example; similar patterns were found for ANC $\leq 0$ and $\leq 50$ $\mu$eq $L^{-1}$. Some differences were observed in Subregions 1E, 2A, and 3B. In Maine (1E), the estimate based on stratified lakes (c) was higher and the estimate based on shallow lakes (e) was lower than the estimate for nonstratified lakes sampled at 1.5 m (a). In Northeastern Minnesota (2A), the estimates based on the same two subpopulations (c and e) were both higher than those for mixed lakes sampled at 1.5 m (a); but when all lakes were included (f), the proportion changed only from 0.524 to 0.570. Shallow lakes (e) in Florida (3B)

Figure 4-13. Classes of ANC ($\mu$eq L$^{-1}$) in lakes sampled in Subregions 3A (Southern Blue Ridge) and 3B (Florida), Eastern Lake Survey-Phase I.



had higher ANC than lakes sampled at 1.5 m (d), producing a decrease in the proportion of lakes with ANC ≤200 μeq L$^{-1}$ from 0.608 for lakes sampled at 1.5 m (d) to 0.551 for all lakes (f).

In general, estimates of the proportion of lakes with ANC ≤200 μeq L$^{-1}$ based on the subpopulations (a - e) were very close to the estimates for all lakes (f). Adding shallow (e) and stratified (c) lakes to the unstratified lakes sampled at 1.5 m (a) had little effect on the population estimates of the proportion of lakes for most subregions. Three subregions (1B, 2B, and 3B) show differences >0.05 in the proportions of lakes with ANC ≤200 μeq L$^{-1}$ between nonstratified (a) and all lakes (f). Subregions 2B and 3B contain a large population of shallow lakes (Table

Table 4-12. **Estimates of Numbers of Lakes with ANC ≤0, ≤50 and ≤200 μeq L$^{-1}$ by State[a], Eastern Lake Survey-Phase I**

| State | Estimated Number of Lakes (N) | Number of Lakes Sampled | ANC (μeq L$^{-1}$) ≤0 (UCL)[b] | ≤50 (UCL)[b] | ≤200 (UCL)[b] |
|---|---|---|---|---|---|
| CT | 346 | 24 | 47 (100) | 47 (100) | 145 (218) |
| FL | 2088 | 138 | 453 (605) | 732 (932) | 1146 (1403) |
| GA | 155 | 54 | 10 (10) | 10 (10) | 49 (63) |
| MA | 926 | 97 | 52 (83) | 239 (311) | 578 (686) |
| ME | 1966 | 225 | 8 (21) | 200 (261) | 1337 (1450) |
| MI | 2073 | 160 | 107 (162) | 368 (522) | 704 (910) |
| MN | 3026 | 174 | 0 (-)[c] | 143 (282) | 1124 (1368) |
| NC | 55 | 30 | 0 (-)[c] | 4 (5) | 35 (48) |
| NH | 639 | 69 | 17 (35) | 171 (229) | 537 (609) |
| NY | 2041 | 191 | 168 (237) | 577 (693) | 1200 (1349) |
| PA | 616 | 106 | 20 (30) | 79 (95) | 284 (363) |
| RI | 113 | 15 | 13 (27) | 33 (54) | 86 (121) |
| SC | 40 | 12 | 0 (-)[c] | 0 (-)[c] | 10 (17) |
| VT | 258 | 28 | 0 (-)[c] | 19 (38) | 90 (121) |
| WI | 3402 | 253 | 41 (68) | 801 (1008) | 1690 (2027) |

[a] Includes only states in which more than ten lakes were sampled.
[b] Upper confidence limit, $N_{cu}$, shown in parentheses.
[c] (-) = undefined.

4-7) that strongly influence these proportions. Therefore, eliminating lakes not originally designated in the protocol for sampling (i.e., shallow and stratified lakes) would substantially reduce the estimated number of lakes with ANC ≤200 μeq L$^{-1}$ in Subregion 1B from 572 (f) to 332 (a), in Subregion 2B from 438 (f) to 245 (a), and in Subregion 3B from 1156 (f) to 1042 (a). To avoid loss of information on these subpopulations, all population estimates referred to in this report include lakes regardless of thermal stratification status or sample depth.

Table 4-13. **Population Estimates of the Proportion of Lakes with ANC ≤200 μeq L$^{-1}$ for Six Subpopulations,* Eastern Lake Survey -Phase I**

| | | ANC ≤200 μeq L$^{-1}$ a | b | c | d | e | f |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.703 | 0.706 | 0.696 | 0.702 | 0.738 | 0.705 |
| | 1B | 0.328 | 0.349 | (0.000)** | 0.381 | 0.404 | 0.387 |
| | 1C | 0.675 | 0.671 | 0.741 | 0.681 | 0.655 | 0.676 |
| | 1D | 0.585 | 0.576 | (0.000)** | 0.581 | 0.554 | 0.573 |
| | 1E | 0.703 | 0.662 | (0.826) | 0.709 | 0.496 | 0.668 |
| REGION | 1 | 0.604 | 0.589 | 0.779 | 0.617 | 0.537 | 0.600 |
| SUBREGION | 2A | 0.524 | 0.561 | (0.767) | 0.536 | 0.744 | 0.570 |
| | 2B | 0.471 | 0.412 | 0.449 | 0.466 | 0.335 | 0.417 |
| | 2C | 0.577 | 0.562 | (0.000)** | 0.582 | (0.000)** | 0.567 |
| | 2D | 0.302 | 0.324 | (0.000)** | 0.291 | 0.442 | 0.313 |
| REGION | 2 | 0.414 | 0.420 | 0.338 | 0.407 | 0.451 | 0.414 |
| SUBREGION | 3A | 0.371 | 0.327 | (0.000)** | 0.388 | (0.000)** | 0.343 |
| | 3B | 0.608 | 0.551 | --------- | 0.606 | 0.296 | 0.551 |

*a = nonstratified lakes sampled at 1.5 m
b = all nonstratified lakes
c = all stratified lakes
d = lakes sampled at 1.5 m
e = lakes sampled at 0.5 m (shallow)
f = all lakes

**Proportions in parentheses are based on sample sizes of <10; in Subregion 3B, no stratified lakes were sampled.

## *4.5.2 pH*

### 4.5.2.1 Reference Values

The two reference values chosen for pH were 5.0 and 6.0. A pH of ≤5.0 was defined as low pH. The tables for pH ≤6.0 are cumulative; i.e., they include lakes ≤5.0.

### 4.5.2.2 Northeast

In the Northeast, lakes with low pH were most common in the Adirondacks, Poconos, Cape Cod, and southwestern New Hampshire (Figure 4-14). The highest number (128) and percentage (10%) of low pH lakes were estimated for the Adirondacks (1A); however, the largest area (2,295 ha) and areal percentage estimates (6%) of low pH lakes were for Southern New England (1D; Table 4-14). Maine (1E) had few low pH lakes (8) and had the fewest (74) lakes with pH ≤6.0 (Table 4-15). The highest number (343) and percentage (27%) and the largest area (12,375 ha) of lakes with pH ≤6.0 were also found in the Adirondacks (1A), but the highest areal percentage (14%) of lakes with pH ≤6.0 occurred in the Poconos/Catskills (1B).

### 4.5.2.3 Upper Midwest

Lakes in the Upper Midwest with low pH were most common in Northcentral Wisconsin (2C) and the Upper Peninsula of Michigan (2B) near Whitefish Point (Figure 4-15). The highest number (99), greatest area (812 ha), and corresponding percentages (9% and 2%) of low pH lakes were estimated to occur in the Upper Peninsula of Michigan (2B). No low pH lakes were sampled in Subregion 2A or 2D (Table 4-14). The highest number (411), largest area (6,276 ha), and highest percentages for both number (28%) and area (6%) of lakes with pH ≤6.0 were estimated for Northcentral Wisconsin (2C). Northeastern Minnesota (2A) had the fewest number (20), least area (255 ha), and lowest corresponding percentages (1% and 0.2%) of lakes with pH ≤6.0 (Table 4-15).

### 4.5.2.4 Southeast

In the Southeast, lakes with low pH were located in the highland region of the Florida Panhandle, southern Georgia, and the central ridge of the Florida Peninsula (Figure 4-16). No low pH lakes were sampled in the Southern Blue Ridge (3A) and only one lake with pH ≤6.0 (Tables 4-8 and 4-9). Florida (3B) was estimated to have the most low pH lakes (12% or 259 lakes comprising 7,936 ha) and the most lakes with pH ≤6.0 of any ELS-I subregion (33% or 687 lakes comprising 21,635 ha).

### 4.5.2.5 Estimates by State for pH

Population estimates for lakes with pH ≤5.0 and ≤6.0 were calculated for each state. As with ANC,

**Figure 4-14.** Classes of pH in lakes sampled in Region 1 (Northeast), Eastern Lake Survey-Phase I. (Symbols appearing offshore from Subregion 1E designate lakes sampled on islands.)

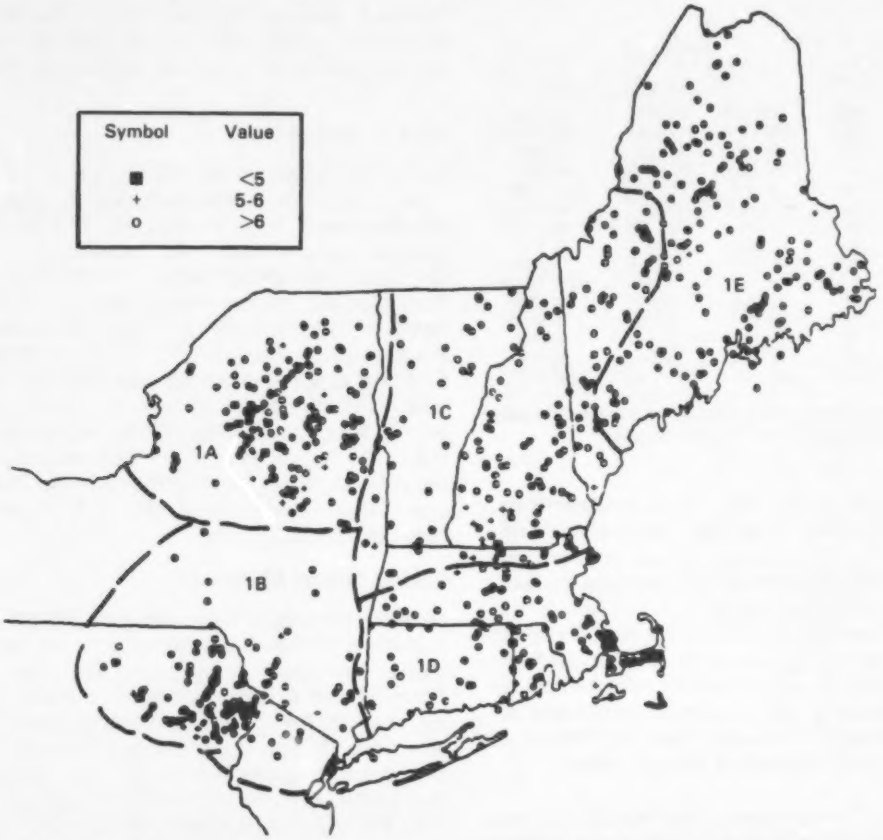


**Table 4-14.** Population Estimates of Lakes with pH ≤ 5.0, Eastern Lake Survey-Phase I

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.100 | 128 | 179 | 0.017 | 1962 | 2977 |
| | 1B | 0.008 | 12 | 20 | 0.019 | 513 | 847 |
| | 1C | 0.017 | 25 | 46 | 0.003 | 194 | 372 |
| | 1D | 0.050 | 66 | 114 | 0.063 | 2295 | 4555 |
| | 1E | 0.005 | 8 | 21 | 0.001 | 95 | 242 |
| REGION | 1 | 0.034 | 240 | 314 | 0.012 | 5059 | 7570 |
| SUBREGION | 2A | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 2B | 0.094 | 99 | 153 | 0.024 | 812 | 1251 |
| | 2C | 0.021 | 31 | 55 | 0.003 | 252 | 468 |
| | 2D | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| REGION | 2 | 0.015 | 130 | 189 | 0.002 | 1064 | 1553 |
| SUBREGION | 3A | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 3B | 0.124 | 259 | 385 | 0.120 | 7936 | 12666 |

$p_c$ = estimated proportion of lakes with pH ≤ 5.0.
$\hat{N}_c$ = estimated number of lakes with pH ≤ 5.0.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of lake area with pH ≤ 5.0.
$\hat{A}_c$ = estimated area of lakes with pH ≤ 5.0.
$A_{cu}$ = 95% upper confidence limit for $A_c$.
(-) = undefined.

these estimates refer only to the portions of the states covered by the ELS-I shown in Section 2.2.1 (Figures 2-1 to 2-4). No lakes with pH ≤5.0 were sampled in Minnesota, North Carolina, Rhode Island, South Carolina and Vermont (Table 4-16). More than 100 lakes in this category were estimated for three states: Florida (249), Michigan (103) and New York (128). States with the highest numbers of lakes estimated to have pH ≤6.0 were: Florida (677), Massachusetts (180), Michigan (330), Minnesota (103), New Hampshire (126), New York (384) and Wisconsin (386).

## 4.6 Regional and Subregional Population Estimates for Other Primary Variables

### *4.6.1 Sulfate*

The data from the ELS-I were examined and two reference values for $SO_4^{-2}$ were arbitrarily selected for comparison, ≥50 and ≥150 $\mu$eq $L^{-1}$. These reference values were not selected to represent or imply a background or critical level of $SO_4^{-2}$, but are discussed to illustrate differences among areas.

Figure 4-15. Classes of pH in lakes sampled in Region 2 (Upper Midwest), Eastern Lake Survey -Phase I. (Symbols appearing offshore from Subregion 2A designate lakes sampled on islands.)

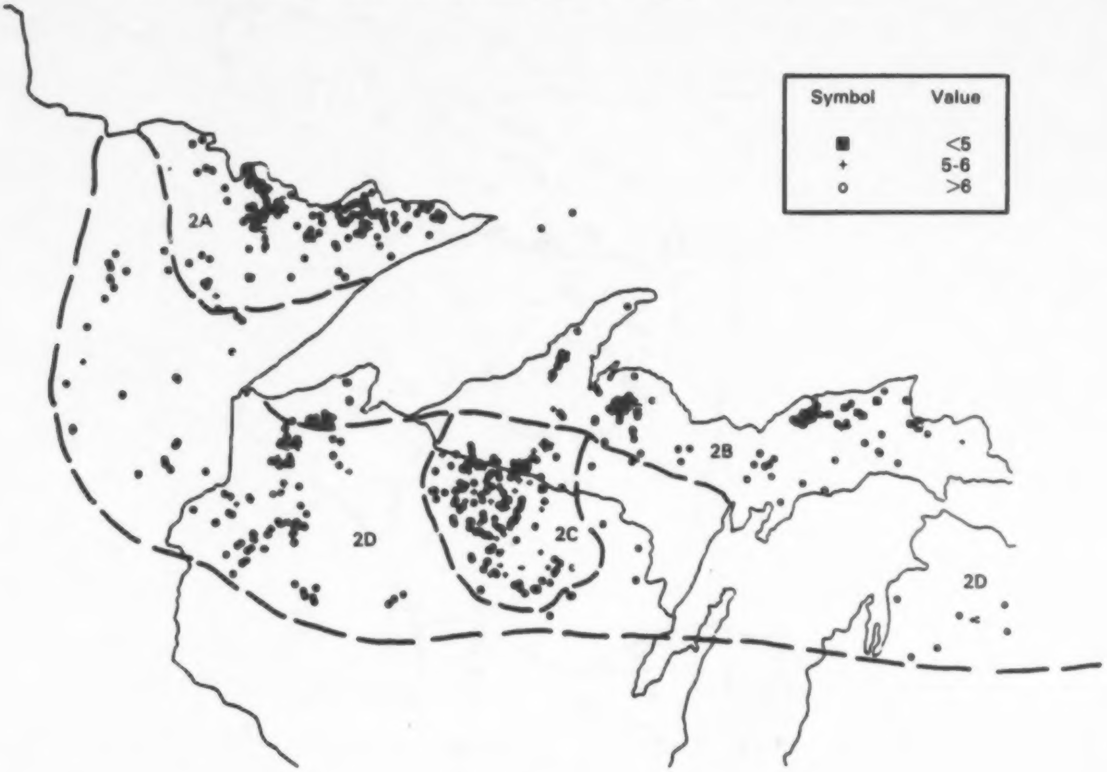


Table 4-15. Population Estimates of Lakes with pH ≤ 6.0, Eastern Lake Survey-Phase I

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.266 | 343 | 418 | 0.104 | 12375 | 19695 |
| | 1B | 0.078 | 116 | 179 | 0.141 | 3793 | 6779 |
| | 1C | 0.129 | 191 | 254 | 0.065 | 4713 | 7298 |
| | 1D | 0.146 | 192 | 260 | 0.110 | 3988 | 6400 |
| | 1E | 0.048 | 74 | 111 | 0.005 | 932 | 1484 |
| REGION | 1 | 0.129 | 916 | 1056 | 0.060 | 25800 | 34478 |
| SUBREGION | 2A | 0.014 | 20 | 43 | 0.002 | 255 | 508 |
| | 2B | 0.177 | 185 | 252 | 0.047 | 1595 | 2204 |
| | 2C | 0.277 | 411 | 489 | 0.064 | 6276 | 8128 |
| | 2D | 0.045 | 202 | 393 | 0.010 | 2273 | 4907 |
| REGION | 2 | 0.096 | 818 | 1036 | 0.021 | 10399 | 13686 |
| SUBREGION | 3A | 0.004 | 1 | 2 | 0.001 | 13 | 18 |
| | 3B | 0.327 | 687 | 878 | 0.327 | 21635 | 28889 |

$p_c$ = estimated proportion of lakes with pH ≤ 6.0.
$\hat{N}_c$ = estimated number of lakes with pH ≤ 6.0.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of lake area with pH ≤ 6.0.
$\hat{A}_c$ = estimated area of lakes with pH ≤ 6.0.
$A_{cu}$ = 95% upper confidence limit for $A_c$.

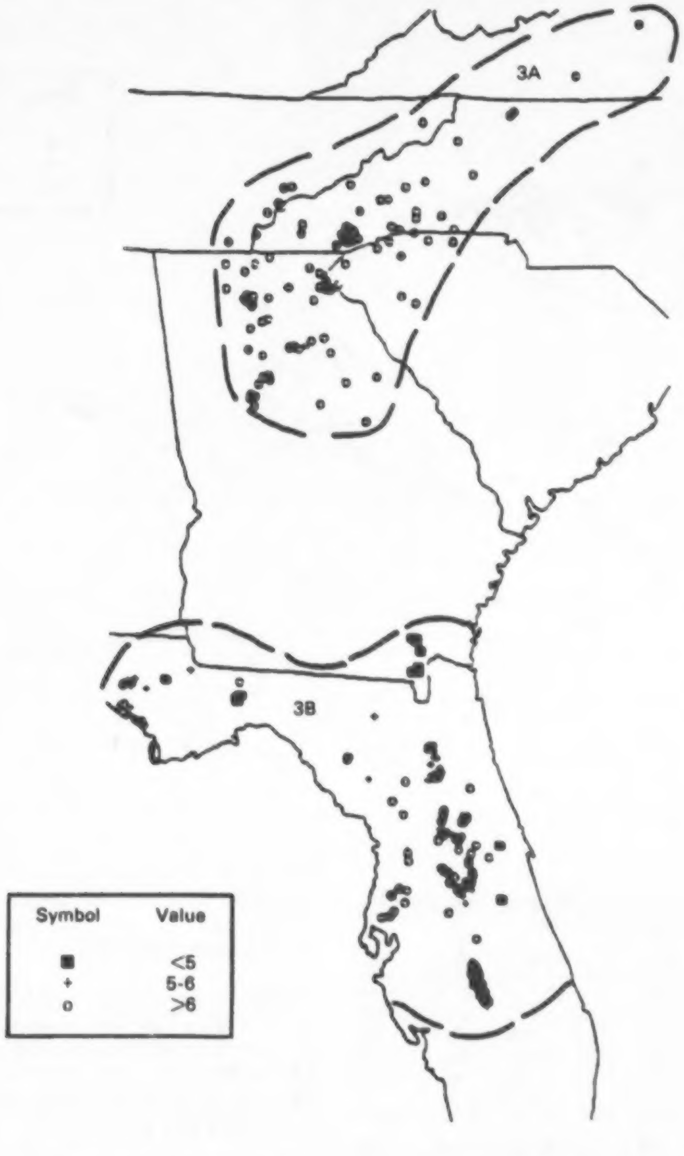
Tables 4-17 and 4-18 summarize population estimates for each subregion based on values of ≥50 and ≥150 $\mu$eq $L^{-1}$. The 1-F(x) and 1-G(x) curves for $SO_4^{-2}$ are found in Volume II.

Within the Northeast, nearly all lakes were estimated to have $SO_4^{-2}$ concentrations ≥50 $\mu$eq $L^{-1}$ (Table 4-17). More than 99 percent of all lakes in Subregions 1A-1D had $SO_4^{-2}$ values ≥50 $\mu$eq $L^{-1}$. In Maine (1E), 88.5 percent of the lakes were estimated to have $SO_4^{-2}$ ≥50 $\mu$eq $L^{-1}$.

The Poconos/Catskills (1B) were estimated to have the largest number of lakes (829, 56%) with $SO_4^{-2}$ concentrations ≥150 $\mu$eq $L^{-1}$ (Table 4-18). Southern New England (1D) also had a large number of lakes (604 or 46%) with $SO_4^{-2}$ concentrations ≥150 $\mu$eq $L^{-1}$. Only 16 lakes (1%) in Maine (1E), were estimated to have $SO_4^{-2}$ concentrations ≥150 $\mu$eq $L^{-1}$. The Adirondacks (1A) had the largest lake area (21,987 ha) with $SO_4^{-2}$ concentrations ≥150 $\mu$eq $L^{-1}$.

In the Upper Midwest, the largest number of lakes (495, 11%) with $SO_4^{-2}$ ≥150 $\mu$eq $L^{-1}$ was located in

**Figure 4-16.** Classes of pH in lakes sampled in Subregions 3A (Southern Blue Ridge) and 3B (Florida), Eastern Lake Survey - Phase I.



the Upper Great Lakes Area (2D; Table 4-18). Northcentral Wisconsin (2C) had the lowest estimated number (16, 1%) of lakes with $SO_4^{-2}$ ≥150 μeq $L^{-1}$. The largest area of lakes having $SO_4^{-2}$ ≥150 μeq $L^{-1}$ was found in Subregion 2B, the Upper Peninsula of Michigan (10,889 ha, 32%). Northcentral Wisconsin had the smallest lake area (445 ha) with $SO_4^{-2}$ ≥150 μeq $L^{-1}$.

The Southern Blue Ridge (3A) contained very few lakes (22, 8%) and a small lake area (1,720 ha, 7%) with $SO_4^{-2}$ ≥150 μeq $L^{-1}$ (Table 4-18). Estimates for Florida (3B) gave the largest number of lakes (846, 40%) and the largest lake area (30,443 ha, 46%) with $SO_4^{-2}$ ≥150 μeq $L^{-1}$ of any subregion.

### *4.6.2 Calcium*

Three reference values originally were selected for calcium based on examination of the ELS-I data. The F(x) and G(x) distributions for calcium, with the statistics for the three reference values, are in-

**Table 4-16.** **Estimates of Numbers of Lakes with pH ≤5.0 and ≤6.0 by State[a], Eastern Lake Survey-Phase I**

| State | Estimated Number of Lakes ($\hat{N}$) | Number of Lakes Sampled | pH<br>≤5.0 (UCL)[b] | pH<br>≤6.0 (UCL)[b] |
|---|---|---|---|---|
| CT | 346 | 24 | 19 (50) | 47 (100) |
| FL | 2088 | 138 | 249 (375) | 677 (868) |
| GA | 155 | 54 | 10 (10) | 10 (10) |
| MA | 926 | 97 | 54 (93) | 180 (243) |
| ME | 1966 | 225 | 8 (21) | 90 (132) |
| MI | 2073 | 160 | 103 (158) | 330 (482) |
| MN | 3026 | 174 | 0 (-)[c] | 103 (236) |
| NC | 55 | 30 | 0 (-)[c] | 1 (2) |
| NH | 639 | 69 | 17 (35) | 126 (177) |
| NY | 2041 | 191 | 128 (179) | 384 (473) |
| PA | 616 | 106 | 13 (20) | 58 (73) |
| RI | 113 | 15 | 0 (-)[c] | 20 (36) |
| SC | 40 | 12 | 0 (-)[c] | 0 (-)[c] |
| VT | 258 | 29 | 0 (-)[c] | 11 (27) |
| WI | 3402 | 253 | 27 (49) | 386 (465) |

[a] Includes only states in which more than ten lakes were sampled.
[b] Upper confidence limit, $N_{cu}$, shown in parentheses.
[c] (-) = undefined.

**Table 4-17.** **Population Estimates of Lakes with Sulfate ≥50 μeq L$^{-1}$, Eastern Lake Survey-Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.994 | 1282 | 1361 | 0.999 | 118664 | 155162 |
| | 1B | 0.998 | 1476 | 1628 | 0.998 | 26818 | 31611 |
| | 1C | 0.995 | 1475 | 1570 | 0.999 | 72321 | 92086 |
| | 1D | 1.000 | 1318 | 1472 | 1.000 | 36403 | 43610 |
| | 1E | 0.885 | 1350 | 1463 | 0.950 | 164696 | 206822 |
| REGION | 1 | 0.973 | 6901 | 7175 | 0.979 | 418903 | 478671 |
| SUBREGION | 2A | 0.737 | 1073 | 1204 | 0.878 | 125600 | 186914 |
| | 2B | 0.791 | 831 | 954 | 0.943 | 32071 | 49992 |
| | 2C | 0.695 | 1028 | 1138 | 0.831 | 81078 | 115637 |
| | 2D | 0.501 | 2261 | 2797 | 0.357 | 81029 | 139434 |
| REGION | 2 | 0.611 | 5193 | 5768 | 0.638 | 319791 | 412988 |
| SUBREGION | 3A | 0.231 | 59 | 82 | 0.300 | 7281 | 13390 |
| | 3B | 0.681 | 1428 | 1720 | 0.783 | 51787 | 67699 |

$p_c$ = estimated proportion of lakes with sulfate ≥50 μeq L$^{-1}$.
$\hat{N}_c$ = estimated number of lakes with sulfate ≥50 μeq L$^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of lake area with sulfate ≥50 μeq L$^{-1}$.
$\hat{A}_c$ = estimated area of lakes with sulfate ≥50 μeq L$^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.

cluded in Volume II. In this volume only the reference value of $Ca^{+2}$ ≤50 μeq L$^{-1}$ is discussed. Table 4-19 summarizes the population estimates for $Ca^{+2}$ derived using this reference value.

In the Northeast, Southern New England (1D) was estimated to contain the largest number of lakes (133, 10%) and the largest lake area (2,164 ha, 6%) having $Ca^{+2}$ concentrations ≤50 μeq L$^{-1}$ (Table 4-19). The Poconos/Catskills (1B) had very few lakes with $Ca^{+2}$ concentrations at or below the reference value of ≤50 μeq L$^{-1}$.

**Table 4-18.** **Population Estimates of Lakes with Sulfate ≥150 μeq L$^{-1}$, Eastern Lake Survey-Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.128 | 165 | 216 | 0.185 | 21987 | 35973 |
| | 1B | 0.561 | 829 | 1003 | 0.533 | 14330 | 18076 |
| | 1C | 0.157 | 232 | 299 | 0.160 | 11577 | 17882 |
| | 1D | 0.458 | 604 | 737 | 0.518 | 18871 | 25309 |
| | 1E | 0.011 | 16 | 34 | 0.006 | 1022 | 2488 |
| REGION | 1 | 0.260 | 1846 | 2082 | 0.158 | 67788 | 84904 |
| SUBREGION | 2A | 0.019 | 28 | 60 | 0.012 | 1661 | 3555 |
| | 2B | 0.066 | 69 | 123 | 0.320 | 10889 | 26780 |
| | 2C | 0.010 | 16 | 40 | 0.005 | 445 | 1154 |
| | 2D | 0.110 | 495 | 813 | 0.024 | 5358 | 9234 |
| REGION | 2 | 0.071 | 608 | 932 | 0.037 | 18353 | 34835 |
| SUBREGION | 3A | 0.085 | 22 | 36 | 0.071 | 1720 | 2737 |
| | 3B | 0.403 | 846 | 1088 | 0.460 | 30443 | 44423 |

$p_c$ = estimated proportion of lakes with sulfate ≥150 μeq L$^{-1}$.
$\hat{N}_c$ = estimated number of lakes with sulfate ≥150 μeq L$^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of lake area with sulfate ≥150 μeq L$^{-1}$.
$\hat{A}_c$ = estimated area of lakes with sulfate ≥150 μeq L$^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.

**Table 4-19.** **Population Estimates of Lakes with Calcium ≤50 μeq L$^{-1}$, Eastern Lake Survey-Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.083 | 108 | 154 | 0.014 | 1618 | 2579 |
| | 1B | 0.004 | 6 | 11 | 0.003 | 93 | 154 |
| | 1C | 0.042 | 63 | 100 | 0.021 | 1534 | 3225 |
| | 1D | 0.101 | 133 | 183 | 0.059 | 2164 | 3763 |
| | 1E | 0.032 | 49 | 80 | 0.003 | 561 | 956 |
| REGION | 1 | 0.051 | 359 | 442 | 0.014 | 5970 | 8520 |
| SUBREGION | 2A | 0.019 | 28 | 60 | 0.002 | 234 | 495 |
| | 2B | 0.160 | 168 | 235 | 0.044 | 1496 | 2177 |
| | 2C | 0.219 | 324 | 400 | 0.047 | 4608 | 6211 |
| | 2D | 0.057 | 256 | 450 | 0.016 | 3564 | 6451 |
| REGION | 2 | 0.091 | 776 | 997 | 0.020 | 9902 | 13284 |
| SUBREGION | 3A | 0.120 | 31 | 42 | 0.203 | 4927 | 6858 |
| | 3B | 0.192 | 402 | 551 | 0.186 | 12289 | 17763 |

$p_c$ = estimated proportion of lakes with calcium ≤50 μeq L$^{-1}$.
$\hat{N}_c$ = estimated number of lakes with calcium ≤50 μeq L$^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of lake area with calcium ≤50 μeq L$^{-1}$.
$\hat{A}_c$ = estimated area of lakes with calcium ≤50 μeq L$^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.

For estimates within the Upper Midwest, Northcentral Wisconsin (2C) had the largest number of lakes (324, 22%) and largest lake area (4,608 ha, 5%) with $Ca^{+2}$ values ≤50 μeq L$^{-1}$ (Table 4-19). The Upper Peninsula of Michigan (2B) also had a high percentage (16%) of lakes with $Ca^{+2}$ concentrations ≤50 μeq L$^{-1}$. The Upper Great Lakes Area (2D) had 256 lakes (6%) and a lake area of 3,564 ha (1.6%) with $Ca^{+2}$ values ≤50 μeq L$^{-1}$. Few lakes with low $Ca^{+2}$

concentrations were located in Northeastern Minnesota (2A).

In the Southern Blue Ridge (3A), 12 percent of the lakes and 20 percent of the lake area were estimated to have $Ca^{+2} \leq 50$ µeq $L^{-1}$ (Table 4-19). Florida (3B) had the most lakes (402, 19%) of any subregion with $Ca^{+2}$ values $\leq 50$ µeq $L^{-1}$.

### *4.6.3 Extractable Aluminum*

Monomeric aluminum (Al) can be toxic to fish at concentrations as low as 100-200 µg $L^{-1}$ unless high concentrations of chelators are also present (Driscoll et al. 1980; Baker and Schofield 1982; Baker 1984). Darkwater and clearwater lakes are defined here as having true color >30 PCU and ≤30 PCU, respectively. For this report, it was assumed that darkwater lakes have sufficient organic material to complex monomeric forms of aluminum. Therefore, population estimates based on reference values for extractable Al are presented for clearwater lakes only. Reference values ≥50, ≥100, and ≥150 µg $L^{-1}$ were selected to bracket the lowest toxic concentrations cited above. Cumulative frequency and areal distributions [1−F(x) and 1−G(x)] (Section 4.3.2.1) for extractable aluminum are provided in Volume II.

The largest estimated number of clearwater lakes (120, 14%) having extractable Al concentrations ≥50 µg $L^{-1}$ (Table 4-20) occurred in the Adirondacks (1A). No clearwater lakes with concentrations exceeding 50 µg $L^{-1}$ were estimated for Maine (1E), Northeastern Minnesota (2A), the Upper Great Lakes Area (2D), or the Southern Blue Ridge (3A). Other subregions contained a small percentage of clearwater lakes, ranging between 1 and 7% with extractable Al in excess of 50 µg $L^{-1}$.

The largest number of lakes having extractable Al concentrations ≥100 µg $L^{-1}$ also occurred in the Adirondacks (100, 12%). Four additional subregions, Poconos/Catskills (1B), Southern New England (1D), the Upper Peninsula of Michigan (2B), and Florida (3B), were estimated to have small percentages of lakes with extractable Al ≥100 µg $L^{-1}$.

In Subregion 1A, 82 (10%) of the lakes were estimated to have concentrations of extractable Al ≥150 µg $L^{-1}$ (Table 4-21). Other subregions having clearwater lakes with extractable Al concentrations ≥150 µg $L^{-1}$ (Table 4-22) occurred in the Poconos/Catskills (1B, 3) Southern New England (1D, 7), the Upper Peninsula of Michigan (2B, 2), and Florida (3B, 14). No clearwater lakes in other subregions had extractable Al concentrations ≥150 µg $L^{-1}$.

### *4.6.4 Dissolved Organic Carbon*

Reference values of 2 mg $L^{-1}$ and 6 mg $L^{-1}$ were used to characterize lakes with respect to DOC. In lakes with DOC concentrations ≥6 mg $L^{-1}$, organic anions are likely to be important in contributing to

**Table 4-20. Population Estimates of Clearwater Lakes with Extractable Aluminum ≥50 µg $L^{-1}$, Eastern Lake Survey -Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.144 | 120 | 169 | 0.025 | 2072 | 3124 |
| | 1B | 0.060 | 66 | 128 | 0.127 | 2787 | 5738 |
| | 1C | 0.018 | 19 | 39 | 0.016 | 1021 | 2525 |
| | 1D | 0.040 | 33 | 67 | 0.044 | 1079 | 2614 |
| | 1E | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| REGION | 1 | 0.052 | 237 | 325 | 0.025 | 6959 | 10758 |
| SUBREGION | 2A | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 2B | 0.021 | 11 | 17 | 0.015 | 196 | 318 |
| | 2C | 0.009 | 8 | 21 | 0.001 | 44 | 112 |
| | 2D | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| REGION | 2 | 0.005 | 19 | 33 | 0.001 | 240 | 380 |
| SUBREGION | 3A | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 3B | 0.074 | 69 | 114 | 0.127 | 4600 | 8750 |

$p_c$ = estimated proportion of clearwater lakes with extractable aluminum ≥50 µg $L^{-1}$.
$\hat{N}_c$ = estimated number of clearwater lakes with extractable aluminum ≥50 µg $L^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of clearwater lake area with extractable aluminum ≥50 µg $L^{-1}$.
$\hat{A}_c$ = estimated area of clearwater lakes with extractable aluminum ≥50 µg $L^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.
(-) = undefined.

**Table 4-21. Population Estimates of Clearwater Lakes with Extractable Aluminum ≥100 µg $L^{-1}$, Eastern Lake Survey -Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.121 | 100 | 146 | 0.022 | 1784 | 2789 |
| | 1B | 0.029 | 32 | 76 | 0.098 | 2149 | 4966 |
| | 1C | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 1D | 0.008 | 7 | 16 | 0.002 | 40 | 101 |
| | 1E | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| REGION | 1 | 0.030 | 139 | 203 | 0.014 | 3973 | 6965 |
| SUBREGION | 2A | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 2B | 0.004 | 2 | 4 | 0.007 | 94 | 199 |
| | 2C | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 2D | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| REGION | 2 | 0.000 | 2 | 4 | 0.000 | 94 | 199 |
| SUBREGION | 3A | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 3B | 0.044 | 40 | 76 | 0.064 | 2324 | 5656 |

$p_c$ = estimated proportion of clearwater lakes with extractable aluminum ≥100 µg $L^{-1}$.
$\hat{N}_c$ = estimated number of clearwater lakes with extractable aluminum ≥100 µg $L^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of clearwater lake area with extractable aluminum ≥100 µg $L^{-1}$.
$\hat{A}_c$ = estimated area of clearwater lakes with extractable aluminum ≥100 µg $L^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.
(-) = undefined.

**Table 4-22.** **Population Estimates of Clearwater Lakes with Extractable Aluminum ≥150 μg $L^{-1}$, Eastern Lake Survey--Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.099 | 82 | 124 | 0.017 | 1439 | 2377 |
| | 1B | 0.003 | 3 | 8 | 0.005 | 101 | 239 |
| | 1C | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 1D | 0.008 | 7 | 16 | 0.002 | 40 | 101 |
| | 1E | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| REGION | 1 | 0.020 | 92 | 135 | 0.006 | 1580 | 2531 |
| SUBREGION | 2A | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 2B | 0.004 | 2 | 4 | 0.007 | 94 | 199 |
| | 2C | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 2D | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| REGION | 2 | 0.000 | 2 | 4 | 0.000 | 94 | 199 |
| SUBREGION | 3A | 0.000 | 0 | (-) | 0.000 | 0 | (-) |
| | 3B | 0.015 | 14 | 35 | 0.003 | 103 | 229 |

$p_c$ = estimated proportion of clearwater lakes with extractable aluminum ≥150 μg $L^{-1}$.
$\hat{N}_c$ = estimated number of clearwater lakes with extractable aluminum ≥150 μg $L^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of clearwater lake area with extractable aluminum ≥150 μg $L^{-1}$.
$\hat{A}_c$ = estimated area of clearwater lakes with extractable aluminum ≥150 μg $L^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.
(-) = undefined.

the sum of anions (Oliver et al. 1983). The ion balance in lakes having DOC concentrations of 2 to 6 mg $L^{-1}$ can be dominated either by organic anions or bicarbonate or carbonate ions, depending on pH. Population estimates using these reference values (≤2 mg $L^{-1}$ and ≥6 mg $L^{-1}$) are presented in Tables 4-23 and 4-24. Cumulative frequency and areal distributions [F(x) and G(x); 1-F(x) and 1-G(x)] are presented in Volume II.

Southern New England (1D) contained the most lakes (238, 18%) in the Northeast with DOC concentrations ≤2 mg $L^{-1}$ (Table 4-23). In other areas of the Northeast, only 4 to 7 percent of the lakes were estimated to have DOC ≤2 mg $L^{-1}$.

The Upper Midwest generally had fewer lakes with DOC concentrations ≤2 mg $L^{-1}$ than the Northeast. Only three lakes (0.2%) in Northeastern Minnesota (2A) had DOC concentrations ≤2 mg $L^{-1}$. Two lakes in Subregion 2D were estimated to have DOC ≤2 mg $L^{-1}$; only 4 percent of the lakes in Subregions 2B and 2C were estimated to have DOC ≤2 mg $L^{-1}$.

Florida (3B) contained the highest number of lakes (242) with DOC concentrations ≤2 mg $L^{-1}$. The highest percentage of lakes with DOC ≤2 mg $L^{-1}$ occurred in the Southern Blue Ridge (3A, 54%). The Southern Blue Ridge contained the largest area (21,255 ha, 88%) of lakes with DOC concentrations ≤2 mg $L^{-1}$.

**Table 4-23.** **Population Estimates of Lakes with DOC ≤2 mg $L^{-1}$, Eastern Lake Survey -Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.074 | 95 | 138 | 0.063 | 7518 | 14564 |
| | 1B | 0.055 | 81 | 143 | 0.151 | 4066 | 7718 |
| | 1C | 0.062 | 92 | 136 | 0.065 | 4682 | 8416 |
| | 1D | 0.180 | 238 | 318 | 0.158 | 5740 | 8469 |
| | 1E | 0.044 | 67 | 103 | 0.060 | 10321 | 22261 |
| REGION | 1 | 0.081 | 572 | 696 | 0.076 | 32327 | 47392 |
| SUBREGION | 2A | 0.002 | 3 | 7 | 0.000 | 64 | 150 |
| | 2B | 0.044 | 46 | 85 | 0.023 | 777 | 1466 |
| | 2C | 0.041 | 61 | 98 | 0.008 | 777 | 1304 |
| | 2D | 0.000 | 2 | 3 | 0.000 | 37 | 73 |
| REGION | 2 | 0.013 | 111 | 165 | 0.003 | 1654 | 2528 |
| SUBREGION | 3A | 0.536 | 138 | 164 | 0.876 | 21255 | 29067 |
| | 3B | 0.115 | 242 | 340 | 0.141 | 9327 | 14289 |

$p_c$ = estimated proportion of lakes with DOC ≤2 mg $L^{-1}$.
$\hat{N}_c$ = estimated number of lakes with DOC ≤2 mg $L^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of lake area with DOC ≤2 mg $L^{-1}$.
$\hat{A}_c$ = estimated area of lakes with DOC ≤2 mg $L^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.

**Table 4-24.** **Population Estimates of Lakes with DOC ≥6 mg $L^{-1}$ Eastern Lake Survey -Phase I**

| | | $p_c$ | $\hat{N}_c$ | $N_{cu}$ | $g_c$ | $\hat{A}_c$ | $A_{cu}$ |
|---|---|---|---|---|---|---|---|
| SUBREGION | 1A | 0.149 | 192 | 249 | 0.038 | 4493 | 6347 |
| | 1B | 0.186 | 274 | 398 | 0.121 | 3247 | 4857 |
| | 1C | 0.275 | 408 | 494 | 0.143 | 10353 | 14556 |
| | 1D | 0.270 | 356 | 462 | 0.224 | 8167 | 12070 |
| | 1E | 0.421 | 643 | 743 | 0.452 | 78303 | 109175 |
| REGION | 1 | 0.264 | 1873 | 2090 | 0.244 | 104563 | 136060 |
| SUBREGION | 2A | 0.760 | 1107 | 1238 | 0.509 | 72732 | 101387 |
| | 2B | 0.567 | 595 | 713 | 0.840 | 28590 | 46581 |
| | 2C | 0.342 | 507 | 609 | 0.133 | 12988 | 20160 |
| | 2D | 0.696 | 3141 | 3692 | 0.491 | 111306 | 162583 |
| REGION | 2 | 0.629 | 5351 | 5938 | 0.450 | 225616 | 287467 |
| SUBREGION | 3A | 0.061 | 16 | 28 | 0.016 | 393 | 680 |
| | 3B | 0.689 | 1445 | 1766 | 0.620 | 41004 | 55386 |

$p_c$ = estimated proportion of lakes with DOC ≥6 mg $L^{-1}$.
$\hat{N}_c$ = estimated number of lakes with DOC ≥6 mg $L^{-1}$.
$N_{cu}$ = 95% upper confidence limit for $N_c$.
$g_c$ = estimated proportion of lake area with DOC ≥6 mg $L^{-1}$.
$\hat{A}_c$ = estimated area of lakes with DOC ≥6 mg $L^{-1}$.
$A_{cu}$ = 95% upper confidence limit for $A_c$.

Maine (1E) had the highest percentage of lakes (42%) with DOC concentrations ≥6 mg $L^{-1}$ in the Northeast, followed by Subregions 1C and 1D with 27.5 percent and 27.0 percent, respectively (Table 4-24). The Adirondacks (1A) had the lowest percentage of high DOC lakes (15%) in the Northeast.

A large number of lakes with DOC concentrations ≥6 mg $L^{-1}$ occurred in the Upper Midwest. The estimated percentage of the total number of such lakes in subregions of the Upper Midwest ranged from 34 percent in Northcentral Wisconsin (2C) to 76 percent in Northeastern Minnesota (2A). The Southern Blue Ridge (3A) contained the smallest percentage (6%) of lakes having high DOC concentrations (≥6 mg $L^{-1}$) of any ELS-I subregion. Florida (3B) contained the second highest number of lakes with DOC concentrations ≥6 mg $L^{-1}$ (1445, 69%).

## 4.7 Statistics for Population Distributions, Primary Variables

Table 4-25 gives the population estimates of the median values for the primary variables: pH, ANC, DOC, extractable Al, $SO_4^{-2}$ and $Ca^{+2}$. The first and fourth quintile values ($Q_1$ and $Q_4$) of the distribution are also given. These quintiles represent the 20th and 80th percentiles of the distribution, respectively.

Median, $Q_1$ and $Q_4$ values are used to compare the distribution, F(x), among subregions and regions. In comparing any two distributions, for example, it is unlikely that the values of these three statistics would be the same if the two distributions were different. Additionally, $Q_1$ values are useful in comparing F(x) distributions of variables for those variables in which interest is primarily focused on the low concentrations (e.g., ANC and pH). For the same reason, $Q_4$ values are useful for those variables for which higher concentrations are of interest (e.g., $SO_4^{-2}$ and extractable Al).

**Table 4-25.** **Primary Variables: First Quintiles ($Q_1$), Medians (M), and Fourth Quintiles ($Q_4$), Eastern Lake Survey-Phase I**

| | | pH | | | ANC (μeq $L^{-1}$) | | | DOC (mg $L^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ |
| SUBREGION | 1A | 5.48 | 6.71 | 7.14 | 14.0 | 111.8 | 250.8 | 2.8 | 4.1 | 5.8 |
| | 1B | 6.64 | 7.02 | 7.36 | 102.2 | 297.4 | 530.5 | 2.9 | 3.8 | 6.0 |
| | 1C | 6.30 | 6.77 | 7.30 | 52.0 | 119.9 | 387.7 | 3.0 | 4.4 | 6.8 |
| | 1D | 6.21 | 6.81 | 7.14 | 39.4 | 161.8 | 402.6 | 2.3 | 4.0 | 6.8 |
| | 1E | 6.57 | 6.91 | 7.31 | 72.1 | 148.4 | 298.4 | 2.9 | 5.2 | 8.4 |
| REGION | 1 | 6.33 | 6.87 | 7.26 | 51.6 | 158.1 | 399.9 | 2.8 | 4.3 | 6.6 |
| SUBREGION | 2A | 6.57 | 6.94 | 7.34 | 98.2 | 184.9 | 403.4 | 5.5 | 9.2 | 12.7 |
| | 2B | 6.07 | 7.10 | 7.82 | 55.5 | 283.6 | 12[illegible].4 | 3.4 | 6.8 | 11.2 |
| | 2C | 5.80 | 6.68 | 7.52 | 15.8 | 93.9 | 600.7 | 3.2 | 4.6 | 8.1 |
| | 2D | 6.63 | 7.39 | 8.07 | 104.0 | 801.7 | 2021.9 | 5.2 | 8.8 | 13.0 |
| REGION | 2 | 6.40 | 7.09 | 7.86 | 78.8 | 359.5 | 1415.5 | 4.4 | 7.5 | 12.1 |
| SUBREGION | 3A | 6.73 | 6.98 | 7.29 | 149.1 | 250.2 | 421.3 | 1.1 | 1.9 | 3.9 |
| | 3B | 5.38 | 6.56 | 7.41 | −7.5 | 83.5 | 713.0 | 4.0 | 8.6 | 13.6 |

| | | Ext Al (μg $L^{-1}$)* | | | $SO_4^{-2}$ (μeq $L^{-1}$) | | | $Ca^{+2}$ (μeq $L^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ |
| SUBREGION | 1A | 2.3 | 7.1 | 29.4 | 104.0 | 118.7 | 141.9 | 76.7 | 144.5 | 277.7 |
| | 1B | 0.9 | 3.0 | 7.2 | 118.1 | 159.3 | 221.0 | 161.2 | 291.4 | 506.6 |
| | 1C | 2.5 | 6.5 | 12.6 | 77.9 | 101.2 | 136.1 | 89.9 | 136.8 | 403.6 |
| | 1D | 1.0 | 2.9 | 9.0 | 108.2 | 141.1 | 190.3 | 82.5 | 186.8 | 378.9 |
| | 1E | 0.8 | 4.5 | 12.4 | 56.4 | 74.6 | 87.8 | 86.7 | 147.2 | 278.1 |
| REGION | 1 | 1.3 | 4.6 | 11.6 | 79.4 | 115.4 | 164.9 | 89.9 | 177.4 | 383.3 |
| SUBREGION | 2A | 0.4 | 1.9 | 3.0 | 46.6 | 62.5 | 83.9 | 98.0 | 143.3 | 329.9 |
| | 2B | 0.0 | 3.0 | 11.9 | 49.1 | 77.7 | 103.5 | 84.4 | 246.3 | 987.5 |
| | 2C | 0.2 | 2.6 | 8.6 | 41.9 | 56.9 | 76.4 | 48.5 | 101.1 | 394.2 |
| | 2D | 0.2 | 3.3 | 8.2 | 29.0 | 50.1 | 85.4 | 87.5 | 522.5 | 1189.5 |
| REGION | 2 | 0.1 | 3.0 | 8.5 | 34.5 | 57.1 | 87.8 | 81.9 | 238.2 | 937.4 |
| SUBREGION | 3A | 0.8 | 1.9 | 2.5 | 19.5 | 31.8 | 59.6 | 68.6 | 104.7 | 252.6 |
| | 3B | 1.0 | 4.5 | 18.6 | 28.4 | 93.7 | 272.4 | 54.2 | 238.3 | 852.9 |

*Clearwater lakes only.

## 4.8 Statistics for Population Distributions, Secondary Variables

This section gives population estimates for the secondary variables measured during the ELS-I. These variables comprise many of the important attributes of lakes and can be used to evaluate the status of the population of lakes. The text and tables are organized to group related variables: nutrients (nitrate, ammonium and total phosphorus); those influencing transparency (true color, Secchi disk transparency and turbidity); cations (potassium, sodium and magnesium); metals (iron, manganese and total aluminum); and other variables (silica, DIC, chloride, conductance and bicarbonate). All values listed are for the estimated population $Q_1$, median and $Q_4$ values for each variable.

### *4.8.1 Nutrients*

For the Northeast, nutrient concentrations were generally low (Table 4-26) compared to values typically found in productive lakes (Wetzel 1983). In many cases, concentrations of total phosphorus or nitrate were at or below the detection limit. Estimated median values for the Northeast were 0.4 μeq $L^{-1}$ for nitrate, 1.4 μeq $L^{-1}$ for ammonium and 9.0 μg $L^{-1}$ for total phosphorus. Among the subregions, median values were generally highest in 1B, followed by 1D. Whereas the estimated $Q_4$ for total phosphorus was 37.2 and 32.2 μg $L^{-1}$ in 1B and 1D,

**Table 4-26.** **Secondary Variables (Nitrate, Ammonium and Total Phosphorus): First Quintiles ($Q_1$), Medians (M), and Fourth Quintiles ($Q_4$), Eastern Lake Survey-Phase I**

| | | $NO_3^-$ (μeq $L^{-1}$) | | | $NH_4^+$ (μeq $L^{-1}$) | | | P-Total (μg $L^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ |
| SUBREGION | 1A | 0.1 | 0.6 | 3.7 | 1.0 | 1.5 | 3.0 | 1.6 | 4.7 | 9.2 |
| | 1B | 0.2 | 0.7 | 6.3 | 1.1 | 2.2 | 7.3 | 12.1 | 21.9 | 37.2 |
| | 1C | 0.1 | 0.3 | 1.0 | 1.0 | 1.3 | 2.4 | 4.8 | 7.4 | 13.5 |
| | 1D | 0.1 | 0.8 | 3.8 | 0.1 | 1.4 | 7.7 | 7.7 | 14.0 | 32.2 |
| | 1E | 0.0 | 0.2 | 0.8 | 0.8 | 1.2 | 1.9 | 2.1 | 5.7 | 11.0 |
| REGION | 1 | 0.1 | 0.4 | 2.2 | 0.9 | 1.4 | 3.8 | 4.0 | 9.0 | 20.6 |
| SUBREGION | 2A | 0.1 | 0.9 | 3.1 | 0.3 | 1.5 | 2.7 | 7.1 | 13.4 | 19.1 |
| | 2B | 0.0 | 0.6 | 1.9 | 1.2 | 0.6 | 3.6 | 5.8 | 12.6 | 18.8 |
| | 2C | 0.1 | 1.0 | 2.6 | 0.5 | 2.2 | 6.1 | 7.9 | 13.7 | 22.7 |
| | 2D | 0.0 | 0.6 | 3.4 | 0.2 | 2.1 | 6.9 | 9.8 | 18.9 | 31.1 |
| REGION | 2 | 0.0 | 0.7 | 3.4 | 0.3 | 1.6 | 5.5 | 8.2 | 16.6 | 26.3 |
| SUBREGION | 3A | 0.6 | 3.1 | 10.0 | 0.5 | 2.2 | 11.0 | 3.0 | 7.0 | 14.8 |
| | 3B | 0.1 | 1.0 | 5.7 | 0.8 | 1.4 | 5.0 | 6.8 | 12.4 | 25.8 |

respectively, the other subregions had $Q_4$ values ranging from 9.2 to 13.5 $\mu g\ L^{-1}$. Similarly, estimated $Q_4$ values of ammonium in Subregions 1B and 1D were more than twice those in other areas. Concentrations of ammonium, nitrate and phosphorus in Maine (1E) were all low (medians = 1.2 $\mu eq\ L^{-1}$, 0.2 $\mu eq\ L^{-1}$ and 5.7 $\mu eq\ L^{-1}$, (respectively). Total phosphorus was also low in the Adirondacks (median = 4.7 $\mu g\ L^{-1}$; $Q_4$ = 9.2 $\mu g\ L^{-1}$).

Estimated median values of nutrients were somewhat higher in the Upper Midwest than in the Northeast. Within the Upper Midwest, concentrations were generally highest in the Upper Great Lakes Area (2D), where the total phosphorus median was 18.9 $\mu g\ L^{-1}$. Total phosphorus concentrations were similar among lakes in Subregions 2A-2C (median values = 12.6 – 13.7 $\mu g\ L^{-1}$).

Nitrate concentrations in the Southern Blue Ridge (3A) were higher at the median (3.1 $\mu eq\ L^{-1}$) than in any other area. Median ammonium values were as high in 3A (2.2 $\mu eq\ L^{-1}$) as in 1B and 2C, and the estimated $Q_4$ exceeded that in all other subregions (11.0 $\mu eq\ L^{-1}$). Total phosphorus was generally low in 3A.

Estimated median and $Q_4$ nitrate values in Florida (3B) were less than in the Southern Blue Ridge (3A), but greater than in the Northeast or Upper Midwest. Ammonium concentrations in Florida were within the range of median and $Q_4$ values estimated for the Northeast and Upper Midwest, as were concentrations of total phosphorus. In Florida, total phosphorus (median = 12.4 $\mu g\ L^{-1}$) was greater at all quintiles than in the Southern Blue Ridge, and exceeded the regional estimates of median and $Q_4$ values in the Northeast.

### *4.8.2 True Color, Turbidity and Secchi Disk Transparency*

The population estimates for true color were similar to those for DOC (Section 4.6.4). With the exception of Subregion 2C, estimated median values of true color for the Upper Midwest and Southeast were greater than those calculated for the Northeast (Table 4-27). True color values in the Northeast at all levels were strikingly similar, with median values from 22 to 25 PCU. The highest median color among subregions in the Midwest (44 PCU) was observed in Northeastern Minnesota, which had a $Q_4$ of 89 PCU. The third highest median (37 PCU) and the highest $Q_4$ (93 PCU) were found in Florida.

Turbidity was generally low and uniform among most subregions. The highest turbidity was found in the Southern Blue Ridge (3A), where 90 percent of the lakes are estimated to be reservoirs. Turbidity was also slightly higher than other subregions in the Poconos/Catskills (1B), which also contain many reservoirs (Section 4.4.2.8). The $Q_4$ value calculated for Southern New England (1D) was also greater than in other subregions of the Northeast.

**Table 4-27. Secondary Variables (True Color, Turbidity and Secchi Disk Transparency): First Quintiles ($Q_1$), Medians (M), and Fourth Quintiles ($Q_4$), Eastern Lake Survey-Phase I**

| | | True Color (PCU) | | | Turbidity (NTU) | | | Secchi Disk Transparency (m) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ |
| SUBREGION | 1A | 10 | 22 | 41 | 0.3 | 0.5 | 0.9 | 1.8 | 2.8 | 4.9 |
| | 1B | 12 | 22 | 33 | 0.8 | 1.4 | 2.8 | 1.2 | 1.8 | 2.6 |
| | 1C | 14 | 24 | 41 | 0.3 | 0.7 | 1.2 | 1.2 | 2.6 | 4.4 |
| | 1D | 11 | 24 | 52 | 0.4 | 0.9 | 2.9 | 0.9 | 1.6 | 3.0 |
| | 1E | 10 | 25 | 46 | 0.4 | 0.6 | 1.0 | 1.2 | 2.6 | 4.7 |
| REGION | 1 | 13 | 24 | 44 | 0.4 | 0.7 | 1.6 | 1.2 | 2.3 | 4.0 |
| SUBREGION | 2A | 24 | 44 | 89 | 0.6 | 1.1 | 1.8 | 1.0 | 1.6 | 2.8 |
| | 2B | 16 | 31 | 74 | 0.6 | 0.9 | 1.6 | 0.9 | 1.5 | 2.9 |
| | 2C | 13 | 24 | 50 | 0.4 | 0.8 | 1.6 | 1.3 | 2.3 | 3.4 |
| | 2D | 15 | 39 | 74 | 0.5 | 1.0 | 2.0 | 1.0 | 1.9 | 3.3 |
| REGION | 2 | 15 | 35 | 76 | 0.5 | 0.9 | 1.9 | 1.0 | 1.9 | 3.3 |
| SUBREGION | 3A | 21 | 36 | 59 | 1.9 | 3.9 | 9.1 | 0.9 | 1.8 | 2.7 |
| | 3B | 14 | 37 | 93 | 0.5 | 0.9 | 2.2 | 1.0 | 1.9 | 3.0 |

Secchi disk transparency represents the average of disappearance and reappearance depth of the disk. Where Secchi disk transparency was equal to the site depth (i.e., where the disk was still visible on the lake bottom), no mean value was calculated. The population estimates for Secchi disk transparency exclude the measurements made on these lakes.

Secchi disk transparency at $Q_1$ was 0.9 – 1.3 m in all subregions, except in the Adirondacks (1A), which had a $Q_1$ value of 1.8 m. The Adirondacks also had the highest median (2.8 m) and $Q_4$ (4.9 m) values of the subregions. Within the Northeast, Secchi disk transparency was also high in 1C (4.4 m at $Q_4$) and 1E (4.7 m at $Q_4$), and substantially lower (2.6 m and 3.0 m at $Q_4$ in 1B and 1D, respectively.

In the Upper Midwest, estimated $Q_1$, median and $Q_4$ values of Secchi disk transparency were greatest in Northcentral Wisconsin (2C), which contains many clearwater seepage systems. The highly colored lakes of Northeastern Minnesota (and also some areas of 2B) had the lowest Secchi disk transparency in the Upper Midwest. Transparencies in the Southeast were similar to lakes in Subregion 2A.

### *4.8.3 Sodium, Potassium and Magnesium*

Within the Northeast, estimated $Q_1$, median and $Q_4$ sodium concentrations were highest in Southern New England (1D), and intermediate in 1B and 1C (Table 4-28). Slightly lower $Q_1$ and median concen-

Table 4-28. Secondary Variables (Sodium, Potassium and Magnesium): First Quintiles ($Q_1$), Medians (M), and Fourth Quintiles ($Q_4$), Eastern Lake Survey-Phase I

| | | $Na^+$ (μeq L$^{-1}$) | | | $K^+$ (μeq L$^{-1}$) | | | $Mg^{+2}$ (μeq L$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ |
| SUBREGION | 1A | 23.3 | 37.5 | 78.4 | 5.8 | 8.5 | 11.6 | 25.2 | 53.9 | 101.3 |
| | 1B | 49.3 | 103.4 | 267.0 | 9.7 | 17.1 | 29.8 | 61.6 | 101.1 | 205.6 |
| | 1C | 44.1 | 70.1 | 253.4 | 7.5 | 11.1 | 22.1 | 32.0 | 49.4 | 111.0 |
| | 1D | 150.5 | 342.3 | 773.0 | 16.6 | 24.7 | 48.1 | 64.3 | 116.7 | 227.4 |
| | 1E | 38.0 | 62.5 | 112.0 | 6.5 | 9.1 | 13.4 | 36.7 | 55.9 | 93.6 |
| REGION | 1 | 38.6 | 82.8 | 285.2 | 7.4 | 12.2 | 24.9 | 37.0 | 69.6 | 150.7 |
| SUBREGION | 2A | 33.6 | 40.1 | 82.1 | 6.5 | 9.2 | 13.8 | 71.2 | 100.4 | 166.5 |
| | 2B | 13.5 | 28.9 | 46.6 | 8.6 | 13.4 | 20.0 | 39.2 | 148.4 | 419.9 |
| | 2C | 9.1 | 30.8 | 65.4 | 10.8 | 14.8 | 19.0 | 29.6 | 58.0 | 238.5 |
| | 2D | 23.3 | 66.5 | 118.3 | 15.2 | 21.1 | 30.6 | 65.5 | 340.4 | 700.7 |
| REGION | 2 | 20.3 | 41.2 | 95.3 | 10.2 | 16.3 | 25.4 | 54.3 | 152.4 | 445.2 |
| SUBREGION | 3A | 89.9 | 103.1 | 156.1 | 21.0 | 39.4 | 57.6 | 44.3 | 76.1 | 117.0 |
| | 3B | 107.4 | 197.9 | 340.1 | 4.6 | 21.6 | 139.6 | 56.8 | 159.9 | 494.5 |

trations and a much lower $Q_4$ concentration were estimated for Maine (1E). The Adirondacks (1A) had the lowest quintile concentrations for sodium in the Northeast. Estimates of concentrations of sodium for the Upper Midwest were less than for most areas of the Northeast and for Subregions 3A and 3B. Subregion 2C had the lowest calculated $Q_1$ concentration and 2D had the highest median and $Q_4$ concentrations in the Upper Midwest. Little interquintile difference ($Q_4 - Q_1$) for sodium was found in Northeastern Minnesota (2A). Estimated median concentrations for sodium in Florida (3B) lakes were higher than in all areas except 1D. Median sodium concentrations in the Southern Blue Ridge were approximately half those in Florida.

The population estimates for potassium showed patterns among subregions similar to those for sodium. The highest concentrations at $Q_4$ in each region were for Subregions 1D, 2D, and 3B. Differences in magnesium among subregions closely paralleled those observed for calcium (Section 4.6.2). Median magnesium concentrations were higher in Subregion 2D; the lowest $Q_1$ values were estimated for Subregions 1A and 2C. Within the Northeast, magnesium was higher in the Poconos/Catskills (1B) and Southern New England (1D). The lowest $Q_1$ was in the Adirondacks (1A) and the lowest $Q_4$ in Maine (1E). Magnesium concentrations in the Upper Midwest were generally higher than those in the Northeast. Within the Upper Midwest, $Q_1$ and median concentrations were lowest in Subregion 2C. Magnesium concentrations in Subregion 2A were similar to the concentrations for sodium and potassium, and had a smaller interquintile range than other subregions.

### 4.6.4 Iron, Manganese and Total Aluminum

The lowest median (19.1 μg L$^{-1}$) and $Q_4$ (68.8 μg L$^{-1}$) values for iron were estimated for Florida (3B), which also had the second lowest $Q_1$ value (3.7 μg L$^{-1}$) of any subregion (Table 4-29). The three highest median and quintile values for iron were estimated for Subregions 1D, 2A and 3A. Within the Northeast, Subregions 1A, 1C and 1E had the three lowest estimates of median iron concentrations. Higher iron concentrations were estimated for Subregion 1B and the highest for Subregion 1D. In the Upper Midwest, iron concentrations in Northeastern Minnesota (2A) were approximately twice that of the other subregions at median values. In Region 2, $Q_4$ values for iron ranged from 196.6 μg L$^{-1}$ in Subregion 2D to 268.2 μg L$^{-1}$ in Subregion 2A. Concentrations of iron in Subregion 3A were similar to those in the Upper Midwest. As mentioned above, Florida (3B) lakes had low levels of iron.

The highest concentration of manganese in the Northeast occurred in the Poconos/Catskills (1B) where the median and $Q_4$ values were 28.1 and 121.4 μg L$^{-1}$, respectively. The lowest median and $Q_4$ values were observed in Maine (1E). The lowest concentrations of manganese occurred in the Upper Midwest where all subregions except Northcentral Wisconsin (2C) had median values of 0.0 μg L$^{-1}$. The Southern Blue Ridge (3A) had the highest concentrations of manganese at all three values ($Q_1$ = 8.6, median = 52.7 and $Q_4$ = 156.5).

For the Northeast, total aluminum was lowest in the Poconos/Catskills (1B) and highest at median and $Q_4$ values in the Adirondacks (1A). Median, $Q_1$ and $Q_4$ values for total aluminum concentration were lower in the Upper Midwest than in the Northeast. The lowest values for total aluminum were estimated for Northcentral Wisconsin (2C) and the Upper Great Lakes Area (2D). The highest $Q_4$ concentrations estimated in the Upper Midwest were found in Subregions 2A and 2B, and these values were similar to those in Subregions 1D and 1E.

Table 4-29. Secondary Variables (Iron, Manganese and Total Aluminum): First Quintiles ($Q_1$), Medians (M), and Fourth Quintiles ($Q_4$), Eastern Lake Survey-Phase I

| | | Fe (μg L$^{-1}$) | | | Mn (μg L$^{-1}$) | | | Al-total (μg L$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ |
| SUBREGION | 1A | 10.6 | 40.9 | 124.0 | 2.1 | 13.9 | 32.9 | 27.1 | 67.2 | 175.6 |
| | 1B | 18.3 | 69.3 | 127.9 | 0.0 | 28.1 | 121.4 | 16.8 | 36.1 | 62.0 |
| | 1C | 13.8 | 40.9 | 99.5 | 3.7 | 11.9 | 32.2 | 28.8 | 58.3 | 117.8 |
| | 1D | 29.4 | 84.0 | 248.3 | 0.0 | 19.0 | 84.1 | 20.3 | 48.1 | 103.6 |
| | 1E | 11.0 | 39.9 | 98.1 | 2.1 | 6.9 | 15.2 | 26.7 | 56.2 | 102.3 |
| REGION | 1 | 14.6 | 49.8 | 136.3 | 1.7 | 11.8 | 41.4 | 23.9 | 49.9 | 111.6 |
| SUBREGION | 2A | 20.3 | 104.9 | 268.2 | 0.0 | 0.0 | 1.8 | 16.0 | 39.8 | 97.0 |
| | 2B | 13.8 | 49.9 | 201.2 | 0.0 | 0.0 | 20.4 | 12.5 | 30.9 | 107.6 |
| | 2C | 9.5 | 53.2 | 238.2 | 0.0 | 7.0 | 29.5 | 9.1 | 21.1 | 45.2 |
| | 2D | 2.1 | 44.0 | 196.6 | 0.0 | 0.0 | 9.1 | 8.0 | 19.7 | 48.1 |
| REGION | 2 | 8.2 | 55.3 | 208.2 | 0.0 | 0.0 | 17.1 | 9.1 | 22.9 | 61.7 |
| SUBREGION | 3A | 29.7 | 83.4 | 255.1 | 8.6 | 52.7 | 156.5 | 39.0 | 81.7 | 185.6 |
| | 3B | 3.7 | 19.1 | 68.8 | 1.0 | 4.2 | 16.0 | 22.9 | 44.4 | 130.6 |

The Southern Blue Ridge (3A) had the highest estimated total aluminum values of any subregion. Concentrations of total aluminum in Florida lakes were similar to those in Subregions 1D and 1E, but the $Q_4$ value for Florida lakes was higher.

### *4.8.5 Other Secondary Variables*

Estimated concentrations of silica were similar for most areas of the Northeast, with the exception of lower values in the Poconos/Catskills (1B) (Table 4-30). The Upper Midwest had higher $Q_4$ values than the Northeast, but only slightly higher medians. An exception to this was Northcentral Wisconsin (2C), where concentrations at the $Q_1$ and median were lower than in any other area in Region 1 or 2. The low concentrations of silica were found in seepage lakes. Concentrations of silica were high in the Southern Blue Ridge (3A); Florida (3B) had the lowest concentrations of any area and, like Northcentral Wisconsin (2C), most are seepage systems.

Dissolved inorganic carbon (DIC) levels were generally low in the Northeast, with slightly higher concentrations in the Poconos/Catskills (1B). In the Upper Midwest, DIC was lowest at $Q_1$ and median values in Northcentral Wisconsin (2C); it was highest in the Upper Great Lakes Area (2D). The $Q_4$ concentration for Subregion 2D was the highest of any area sampled. The Southern Blue Ridge (3B) had the highest $Q_1$ value, but had a $Q_4$ value that was close to the regional value for the Northeast.

Concentrations of chloride showed patterns similar to those for sodium (Section 4.8.3). Within the Northeast, chloride concentration was lowest in the Adirondacks (1A) and highest in Southern New England (1D). In the Upper Midwest, concentrations were generally low, although some sites in the Upper Great Lakes Area (2D) had higher values ($Q_4$ = 106.2 $\mu$eq L$^{-1}$). Chloride concentrations were high in Florida (3B) ($Q_1$ = 134.7 $\mu$eq L$^{-1}$; $Q_4$ = 537.3 $\mu$eq L$^{-1}$).

As expected, the patterns for conductance paralleled those for major ionic constituents, particularly sodium chloride and ANC. For the Northeast, conductance was lowest in the Adirondacks (1A) and Maine (1E), and highest in the Poconos/Catskills (1B) and Southern New England (1D). In the Upper Midwest, the lowest $Q_1$ and median values were observed in Subregion 2C. The least interquintile difference was observed in Subregion 2A, again related to the relatively uniform water chemistry in Northeastern Minnesota (2A) compared to other areas. High $Q_4$ values of conductance were found in Subregions 2B and 2D. Florida (3B) lakes had $Q_1$ and median values similar to those in Southern New England (1D), and the highest $Q_4$ of any area.

## 4.9 Characteristics of Special Interest Lakes

During the ELS-I, 186 special interest lakes were sampled (Section 2.2.5). Population estimates were not calculated using data from these lakes because they were not selected as part of the probability sample. Consequently, the characteristics of these lakes are summarized separately by region and presented in Table 4-31. Data for each special interest lake are presented in Volume III.

In general, special interest lakes were larger and had greater watershed areas compared to estimated population medians for the lakes in the probability sample. For nearly all variables, median values for the special interest lakes were lower than

**Table 4-30.** Secondary Variables (Silica, Dissolved Inorganic Carbon, Chloride, Conductance and Bicarbonate): First Quintiles ($Q_1$), Medians (M), and Fourth Quintiles ($Q_4$), Eastern Lake Survey -Phase I.

| | | $SiO_2$ (mg L$^{-1}$) | | | DIC (mg L$^{-1}$) | | | $Cl^-$ ($\mu$eq L$^{-1}$) | | | Conductance ($\mu$S cm$^{-1}$) | | | $HCO_3^-$ ($\mu$eq L$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ |
| SUBREGION | 1A | 0.8 | 2.3 | 4.5 | 0.6 | 1.6 | 3.3 | 8.0 | 11.1 | 56.5 | 21.7 | 30.7 | 52.8 | 7.3 | 102.9 | 218.6 |
| | 1B | 0.3 | 1.0 | 2.7 | 1.5 | 4.1 | 7.1 | 43.1 | 109.5 | 312.3 | 39.1 | 63.7 | 105.1 | 91.8 | 258.3 | 459.1 |
| | 1C | 0.8 | 1.9 | 3.8 | 0.6 | 1.6 | 4.6 | 12.2 | 42.7 | 213.0 | 22.2 | 34.9 | 94.6 | 40.2 | 102.6 | 339.6 |
| | 1D | 0.5 | 2.1 | 4.8 | 0.9 | 2.2 | 4.9 | 149.1 | 382.2 | 827.0 | 47.4 | 81.5 | 156.3 | 30.8 | 141.0 | 358.4 |
| | 1E | 0.8 | 1.9 | 3.1 | 1.0 | 1.8 | 3.4 | 10.6 | 32.5 | 88.5 | 23.3 | 33.0 | 48.2 | 57.4 | 122.0 | 264.2 |
| REGION | 1 | 0.6 | 1.9 | 3.8 | 0.9 | 2.1 | 5.0 | 12.1 | 59.6 | 293.6 | 25.3 | 43.3 | 95.4 | 40.7 | 137.4 | 350.8 |
| SUBREGION | 2A | 0.9 | 2.6 | 5.4 | 1.3 | 2.4 | 4.7 | 6.3 | 8.8 | 14.1 | 22.3 | 30.4 | 52.6 | 66.0 | 143.7 | 342.2 |
| | 2B | 0.3 | 2.3 | 6.1 | 1.0 | 4.5 | 14.8 | 6.1 | 10.2 | 22.5 | 20.5 | 47.2 | 132.9 | 29.2 | 274.7 | 1158.5 |
| | 2C | 0.1 | 0.6 | 6.6 | 0.5 | 1.6 | 7.3 | 6.5 | 11.3 | 36.7 | 13.4 | 22.5 | 73.2 | 9.5 | 72.2 | 577.5 |
| | 2D | 0.3 | 2.4 | 9.0 | 1.7 | 9.5 | 22.1 | 11.9 | 22.0 | 106.2 | 24.7 | 91.6 | 198.7 | 70.8 | 762.5 | 1900.0 |
| REGION | 2 | 0.3 | 2.3 | 6.8 | 1.2 | 4.4 | 16.1 | 7.6 | 16.8 | 65.8 | 20.7 | 44.3 | 142.8 | 51.7 | 287.4 | 1279.6 |
| SUBREGION | 3A | 6.8 | 9.0 | 13.6 | 2.3 | 3.7 | 5.3 | 28.7 | 65.7 | 94.9 | 20.[illegible] | 38.5 | 63.9 | 136.6 | 236.5 | 382.3 |
| | 3B | 0.1 | 0.3 | 1.2 | 0.6 | 1.7 | 10.2 | 134.7 | 222.3 | 537.3 | 37.1 | 90.8 | 197.6 | 4.0 | 76.0 | 651.8 |

Table 4-31. Sample Statistics for Special Interest Lakes by Region: Minima (MIN), Medians (MED) and Maxima (MAX), Eastern Lake Survey-Phase I

| | Region 1 (n=115) | | | Region 2 (n=52) | | | Subregion 3A (n=10) | | | Subregion 3B (n=9) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable (Units) | MIN | MED | MAX | MIN | MED | MAX | MIN | MED | MAX | MIN | MED | MAX |
| Lake Area (ha) | 0.9 | 21.2 | 597.7 | 3.2 | 44.6 | 338.2 | 2 | 14.7 | 2861.9 | 16.6 | 81.4 | 722.7 |
| Watershed Area (ha) | 5 | 295 | 13937 | 13 | 228 | 24577 | 109 | 1064.5 | 120474 | 67 | 355 | 5541 |
| Site Depth (m) | 0.6 | 5.2 | 31.1 | 3 | 6.6 | 24.7 | 3 | 6.2 | 60 | 2.7 | 5.5 | 17.7 |
| ANC (μeq $L^{-1}$) | −63.2 | 42.4 | 600.4 | −18.5 | 69.5 | 990.6 | 16.7 | 128.2 | 498.9 | −19.4 | −11.6 | 131.6 |
| pH, closed | 4.2 | 6.4 | 7.6 | 4.9 | 6.4 | 7.7 | 5.9 | 6.8 | 7.2 | 5.0 | 5.2 | 7.0 |
| Sulfate (μeq $L^{-1}$) | 53.5 | 108.8 | 348.1 | 4.6 | 72.4 | 148.4 | 16.1 | 27.3 | 110.6 | 25.4 | 67.2 | 699.6 |
| Calcium (μeq $L^{-1}$) | 25.4 | 85.0 | 536.9 | 26.4 | 85.6 | 632.7 | 14.5 | 79.8 | 286.9 | 26.5 | 41.2 | 376.1 |
| Al-extractable (μg $L^{-1}$) | 0.8 | 11.8 | 291.1 | 0 | 3 | 80.5 | 1 | 2.5 | 8 | 0 | 2 | 64 |
| DOC (mg $L^{-1}$) | 0.1 | 3.1 | 14.3 | 1.1 | 4.2 | 21.3 | 0.7 | 1.6 | 4.1 | 0.5 | 1.7 | 6.7 |
| Conductance (μS $cm^{-1}$) | 13.8 | 23.6 | 164.6 | 8.1 | 20.1 | 98.1 | 7.8 | 19.6 | 75.8 | 14.2 | 30.2 | 169 |
| Chloride (μeq $L^{-1}$) | 6.1 | 11.1 | 1063.9 | 5.1 | 9.4 | 254.2 | 14.8 | 24.1 | 85.5 | 52.9 | [illegible] | 558.6 |
| Sodium (μeq $L^{-1}$) | 3.7 | 30.2 | 1038.8 | 6.5 | 23.3 | 204.9 | 37.4 | 51.1 | 97.0 | 48.9 | [illegible] | 582.9 |
| Potassium (μeq $L^{-1}$) | 2.1 | 8.3 | 35.1 | 6.9 | 12.4 | 23.8 | 7.2 | 15.5 | 34.5 | 2.3 | 3.6 | 91.8 |
| Magnesium (μeq $L^{-1}$) | 8.4 | 31.4 | 310.1 | 19.7 | 55.5 | 422.8 | 9.0 | 36.6 | 244.3 | 21.8 | 44.2 | 358.1 |
| Silica (mg $L^{-1}$) | 0.1 | 1.9 | 11.3 | 0 | 0.2 | 18.5 | 3.3 | 6.0 | 9.9 | 0.1 | 1.0 | 2.8 |
| DIC, open (mg $L^{-1}$) | 0.2 | 0.9 | 6.9 | 0.2 | 1.2 | 11.8 | 0.7 | 1.9 | 6.6 | 0.2 | 0.4 | 1.4 |
| Al-total (μg $L^{-1}$) | 3 | 105.8 | 685 | 0 | 22.5 | 199.5 | 31 | 53 | 360 | 13 | 39 | 200 |
| Nitrate (μeq $L^{-1}$) | 0 | 0.4 | 18.4 | 0 | 0.5 | 9.5 | 0.6 | 1.5 | 34.8 | 0 | 0.4 | 5.6 |
| Ammonium (μeq $L^{-1}$) | 0 | 1.3 | 14.9 | 0 | 1.1 | 9.4 | 0.3 | 1.9 | 40.6 | 0 | 0.9 | 1.6 |
| P, Total (μg $L^{-1}$) | 0 | 5.1 | 31 | 0 | 12.8 | 95 | 2 | 5.8 | 11 | 2 | 4.5 | 23 |
| True Color (PCU) | 0 | 20 | 150 | 5 | 18.8 | 135 | 10 | 27.5 | 55 | 5 | 10 | 70 |
| Secchi Disk Transparency (m) | 0.6 | 3 | 10.8 | 0.9 | 3.1 | 5.5 | 1.6 | 2.3 | 4.4 | 1.5 | 3.7 | 7.0 |

the calculated population medians, with the exception of higher concentrations of sulfate in the Upper Midwest, total aluminum in the Northeast, and silica in Subregion 3B. There were substantial differences between the sample medians of special interest lakes and the estimated population medians in the Northeast for sulfate, silica, nitrate and ammonium.

There are three general categories of special interest lakes: (1) the EPA-sponsored Long-Term Monitoring (LTM) lakes; (2) the lakes recommended by the National Research Council (NRC) as having high quality historical water chemistry data; and (3) other lakes recommended by State resource management agencies. The LTM lakes were originally selected in large part, because they had low concentrations of ANC and it was expected that they would have low ionic concentrations.

It was expected that the special interest lakes recommended by the NRC and State agencies would also have low ANC based on their location in areas previously identified as having populations of low alkalinity lakes (e.g., Adirondacks, New Hampshire, and Northcentral Wisconsin). The sample data for the special interest lakes confirm that these lakes have lower ANC than the lakes selected in the probability sample.

# *Section 5*
# *Results and Discussions of Associations Among Variables*

The primary objectives of the Eastern Lake Survey-Phase I (ELS-I) were to provide estimates of low ANC and low pH lakes in the regions of interest and to characterize the populations of lakes for further study in Phases II and III. The Survey was designed to meet these primary objectives, and as such, the results presented in Section 4 are appropriately presented on a univariate basis. It is also possible to explore relationships among variables using the ELS-I data base.

The purpose of this section (Section 5) of the report is to present briefly an examination of some bivariate and multivariate relationships that may be pertinent to addressing the role of certain variables in lake acidification. However, the focus of these data presentations, as in Section 4, continues to be largely descriptive. The results are presented in a manner that highlights differences and similarities among subregions, but which avoids formal tests of statistical significance among or within subregions. Investigators who desire to use these data to develop predictive models on populations of lakes need to consider how the identification of lake populations may influence model results. In particular, those variables that may be related to alkalinity map classes may need to be treated on a stratum-by-stratum basis (Section 2.2.1).

When evaluating relationships among lakes it is also important to consider that weighting factors differ among subregions. Thus, multivariate models based upon sample data may incorrectly describe a relationship for a population of lakes. Unlike the population estimates presented in Section 4, the relationships presented in Section 5 include data from special interest lakes and lakes >2000 ha unless noted otherwise.

## 5.1 Relationships of pH and ANC

### *5.1.1 Comparison of pH Measurements*

The pH of each lakewater sample was measured five different times on three separate aliquots (Section 2.7). In situ pH was measured using the Hydrolab unit. At the field laboratory, pH was measured on a sample from a syringe sealed from the atmosphere. At the analytical laboratory, subsamples from a single aliquot were prepared for pH measurements at the start of separate titrations for ANC and BNC and a separate subsample equilibrated with the atmosphere. Pair-wise comparisons of these five measurements were made using linear regressions. The results of the regression analyses are presented in Table 5-1, which shows that the regression equations explained 87 to 99 percent of the total variance. Most slopes were significantly different from 1 ($p < 0.05$) indicating that pH measurements were not identical; however, they were comparable and could be calibrated to one another.

**Table 5-1. Comparison of pH Measurements for Regular and Special Interest Lakes, Eastern Lake Survey-Phase I**

| pH Pair | | | | |
|---|---|---|---|---|
| Dependent/Independent Variable | n | Slope | Intercept | $r^2$ |
| Closed system[a]/In situ[b] | 1779 | 0.938 | 0.535 | 0.943 |
| Closed system/Open system (ANC)[c] | 1793 | 0.989 | 0.101 | 0.942 |
| Closed system/Open system (BNC)[d] | 1793 | 0.979 | 0.123 | 0.942 |
| Closed system/Air-equilibrated[e] | 1781 | 0.811 | 0.883 | 0.905 |
| In situ/Open system (ANC) | 1779 | 1.002 | −0.116 | 0.901 |
| In situ/Open system (BNC) | 1779 | 0.991 | −0.087 | 0.899 |
| In situ/Air-equilibrated | 1767 | 0.827 | 0.642 | 0.875 |
| Air-equilibrated/Open system (ANC) | 1781 | 1.166 | −0.617 | 0.954 |
| Air-equilibrated/Open system (BNC) | 1781 | 1.148 | −0.546 | 0.942 |
| Open system (ANC)/Open system (BNC) | 1794 | 0.985 | 0.057 | 0.989 |

[a] Syringe sample, unexposed to the atmosphere.
[b] In situ pH is the value measured in the lake using the Hydrolab.
[c] Laboratory measurement at initiation of the ANC titration.
[d] Laboratory measurement at initiation of the BNC titration.
[e] Laboratory measurement of an aliquot after bubbling with 300 ppm $CO_2$ for 20 minutes. However, complete equilibration with atmospheric $CO_2$ may not have been obtained.

The field laboratory pH measurement was used in interpreting ELS-I data (Section 2.6.4, closed system pH). The field laboratory measurement was performed within 16 hours of collection on a sample that was unexposed to the atmosphere during collection and analysis, minimizing the problem of a change in pH over time caused by $CO_2$ exchange during storage. The measurement in the field laboratory was made using more sophisticated equipment than was used for the in situ measurement, reducing the problem of instrument instability. The closed system pH represented the best single measurement of in situ pH conditions, and hence was used for all population estimates.

The in situ measurement was not selected for use in interpretations because the precision was lower than the field laboratory measurement. The three analytical laboratory pH measurements were not used for data interpretation because the samples either gained or lost $CO_2$ and therefore differed from the value observed in the lake. As shown in Figure 5-1, for closed and open system pH, much of the variation observed between different measurements occured at pH values greater than six. The $r^2$ for pH values $\leq 6.0$ was 0.96; for pH $>6.0$, $r^2$ was 0.83. This pH-dependent variation is consistent with changes caused by $CO_2$ exchange between the sample and the atmosphere. This is supported by comparing closed system pH to air-equilibrated pH. These measurements were made using identical instrumentation yet the regression equation did not have a slope of 1.

### 5.1.2 Relationship Between pH and ANC

Figures 5-2 through 5-5 depict the relationship between closed system pH and ANC for Regions 1 and 2, and Subregions 3A and 3B. Also plotted on each figure is the curve showing the expected relationship between pH and ANC assuming the lakes are

**Figure 5-1.** Closed system pH versus initial open system pH for probability sample lakes and special interest lakes in all regions, Eastern Lake Survey-Phase I.

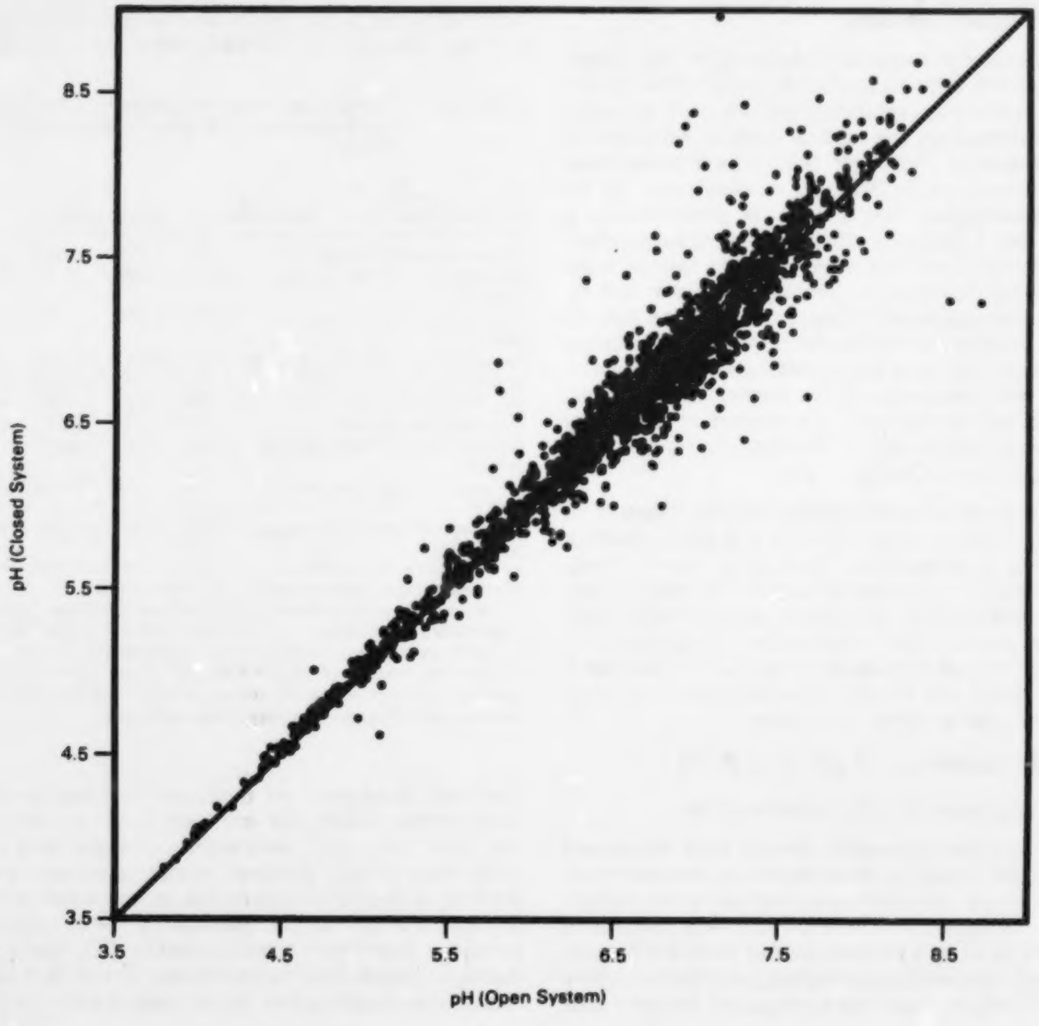
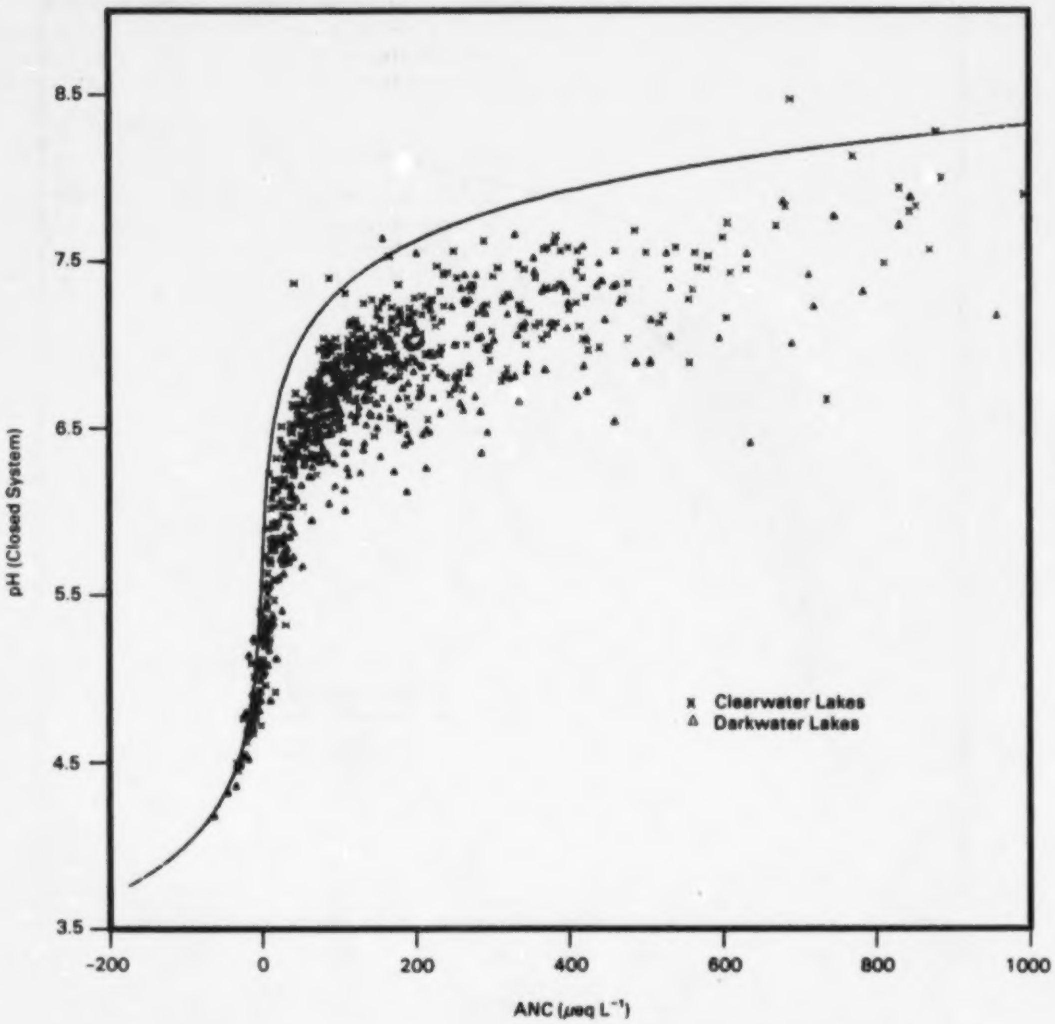


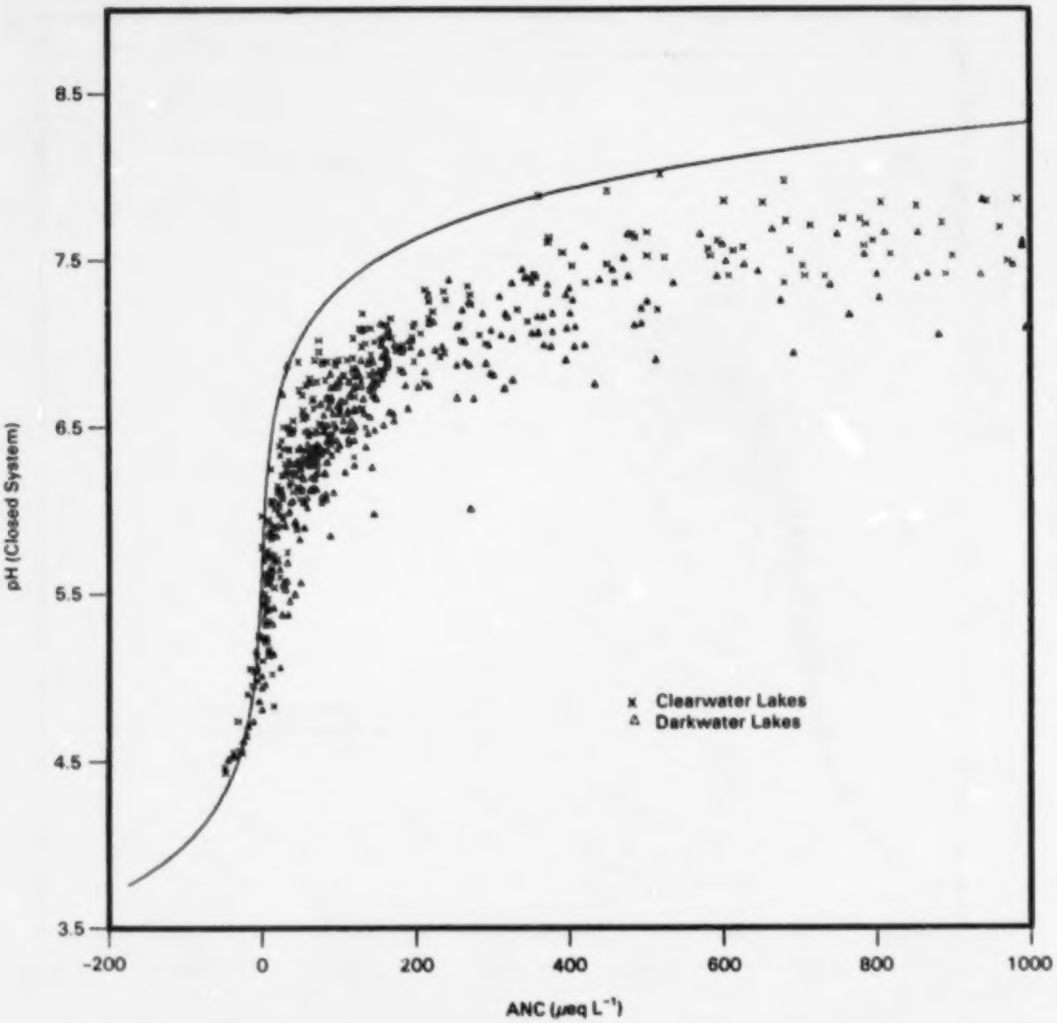
**Figure 5-2.** pH (closed system) versus ANC (μeq $L^{-1}$) for Region I, Eastern Lake Survey-Phase I. (Clearwater lakes (≤30 PCU) are shown as x's and darkwater (>30 PCU) as triangles. The theoretical curve shown was calculated for 25°C and $10^{-3.5}$ atm $CO_2$.)



in equilibrium with atmospheric $CO_2$ ($pCO_2 = 10^{-3.5}$ atm at 25°C; Butler 1982). Clearwater (color ≤30 PCU) and darkwater lakes (color >30 PCU) are represented by X's and triangles, respectively.

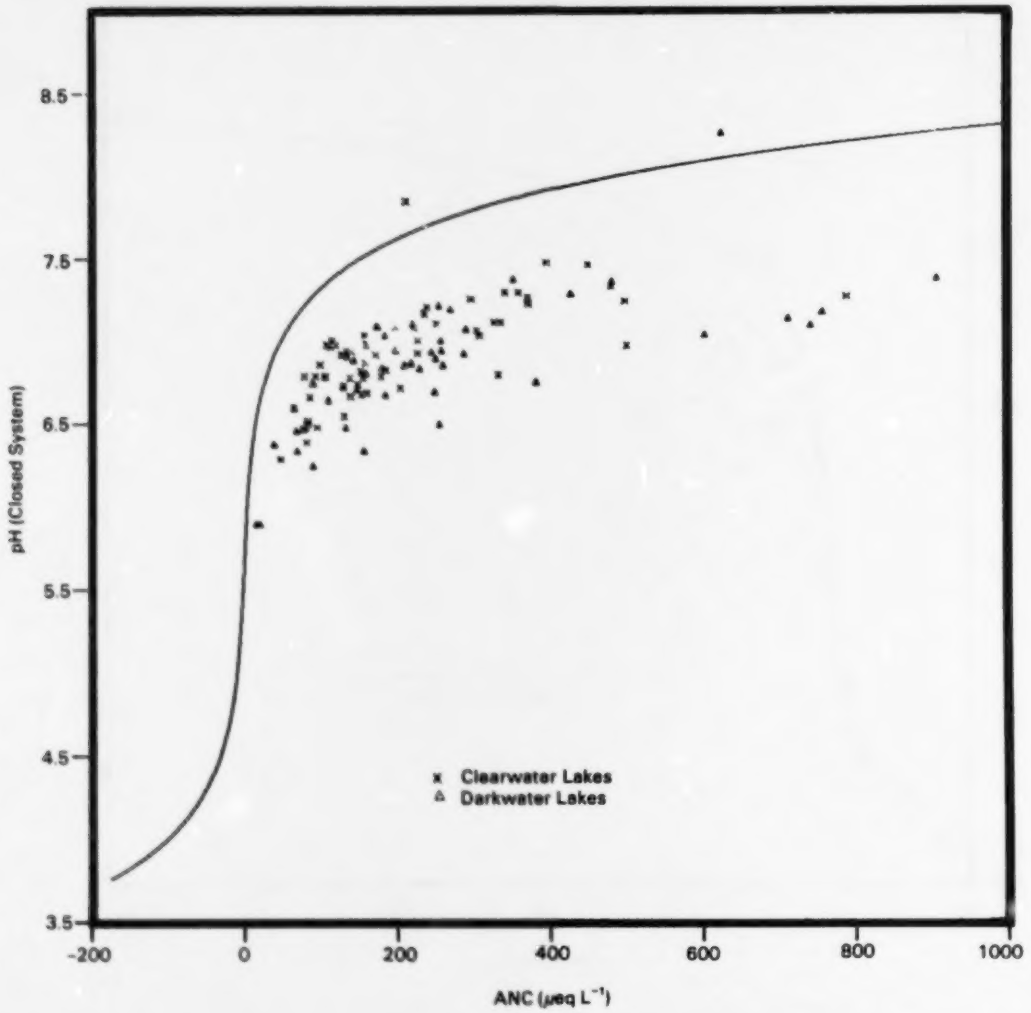
Both the lakewater temperature and the partial pressure of $CO_2$ influence the solubiltiy of $CO_2$ in water (Stumm and Morgan 1981) and the position of the theoretical curve (Butler 1982). The water temperature assumed for calculation of the theoretical curves in Figures 5-2 through 5-6 was 25°C. The field laboratory pH samples, however, were taken from lakes at temperatures below 25°C. The samples were allowed to equilibrate to ambient air temprature but were not allowed to equilibrate with the atmosphere prior to pH measurement. This caused the samples at laboratory temperature to be highly supersaturated with $CO_2$, and resulted in lower pH readings than expected compared to the theoretical curve. One remedy for this problem is to recalculate the theoretical relationship for each region, using the average lake temperature for that region. When this was done, the theoretical curves were still above most data points but not as far above. The theoretical curves shown in the figures, however, were identically calculated for a temperature of 25°C for ease in making comparisons among subregions.

Figure 5-3. pH (closed system) versus ANC ($\mu$eq $L^{-1}$) for Region 2, Eastern Lake Survey-Phase I. (Clearwater lakes (≤30 PCU) are shown as x's and darkwater (>30 PCU) as triangles. The theoretical curve shown was calculated for 25°C and $10^{-3.5}$ atm $CO_2$.)



The theoretical curves also were calculated assuming equilibrium with atmospheric $CO_2$($pCO_2 = 10^{-3.5}$ atm). Data from lakes undersaturated with $CO_2$ will plot above this curve, while data from lakes supersaturated with $CO_2$ will plot below this curve. In all four plots of closed system pH versus ANC, many more lakes fall below than above the curves drawn at both 25°C and at the average lake temperature for that region. In contrast, values of air-equilibrated pH versus ANC closely agree with the expected theoretical relationship (Figure 5-6). Carbon dioxide supersaturation in lakes has been reported by several investigators. Cook et al. (1985) found nonuniform $CO_2$ saturation throughout the water column, with both undersaturation and supersaturation observed in 36 lakes in the Upper Midwest. Partial pressure of $CO_2$ ranged from 0.5 to two times saturation values in Canadian lakes (Schindler and Ruszczynski 1983), indicating that lakes may not be in equilibrium with atmospheric $CO_2$. Drever (1982) reported that $pCO_2$ ranged from $10^{-2}$ to $10^{-3.5}$ atm in most surface waters. Rivers with vegetative covers were found to be supersaturated with $CO_2$ with respect to atmospheric pressure, whereas rivers flowing over exposed basalts approached equilibrium with atmospheric $CO_2$ (Holland 1978). Lakes with appreciable groundwater contributions would also be expected to be supersaturated with $CO_2$. These studies suggest that sources other than the atmosphere control the partial pressure of $CO_2$ in the water column.

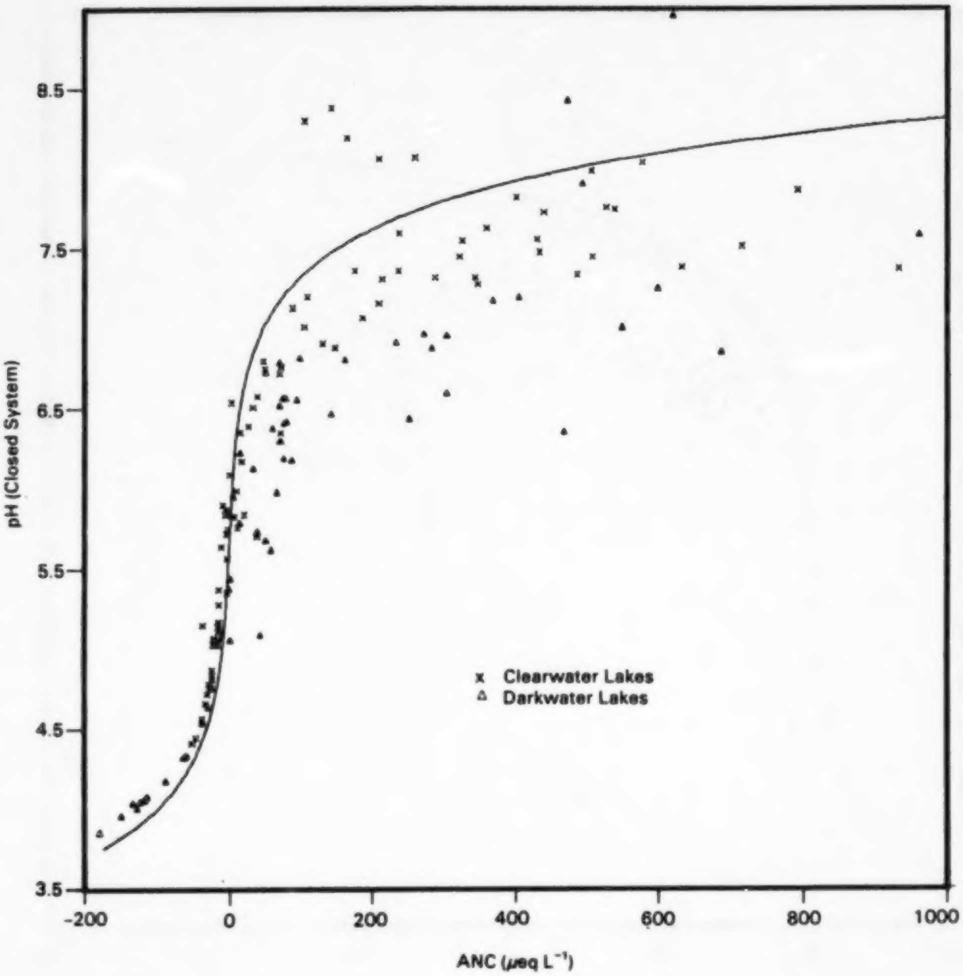
Figure 5-4. pH (closed system) versus ANC ($\mu$eq L$^{-1}$) for Subregion 3A, Eastern Lake Survey-Phase I. (Clearwater lakes ($\leq$30 PCU) are shown as x's and darkwater ($>$30 PCU) as triangles. The theoretical curve shown was calculated for 25°C and $10^{-3.5}$ atm $CO_2$.)



The data were much closer to the theoretical curve at lower values of pH and ANC, indicating that the relative importance of supersaturation with $CO_2$ in these lakes increases with increasing pH and ANC. Lakes with high ANC are likely to be more biologically productive than low ANC lakes (Ryder 1964). Biological activity can strongly affect concentrations of $CO_2$ in lakewater (Moss 1973) often increasing $pCO_2$ values in the water column.

As the theoretical relationship considers strictly bicarbonate alkalinity, the presence of other constituents in lake water may cause measured samples to deviate from the predicted relationship. The presence of weak acids may result in a lower pH and higher ANC than those predicted by the theoretical relationship, and thus, samples containing high concentrations of weak acids may plot below the theoretical line. In both Regions 1 and 2, at low ANC values, clearwater lakes were closer to the theoretical curve than were darkwater lakes. This may be explained by the observation that darkwater lakes have higher DOC (Section 5.2.6.1), and therefore higher weak acid concentrations. Weak acids are more likely to affect the ANC versus pH curve in this region of the curve than at higher pH and ANC values (Small and Sutton 1986).

Figure 5-5. pH (closed system) versus ANC ($\mu$eq $L^{-1}$) for Subregion 3B, Eastern Lake Survey-Phase I. (Clearwater lakes (≤30 PCU) are shown as x's and darkwater (>30 PCU) as triangles. The theoretical curve shown was calculated for 25°C and $10^{-3.5}$ atm $CO_2$.)



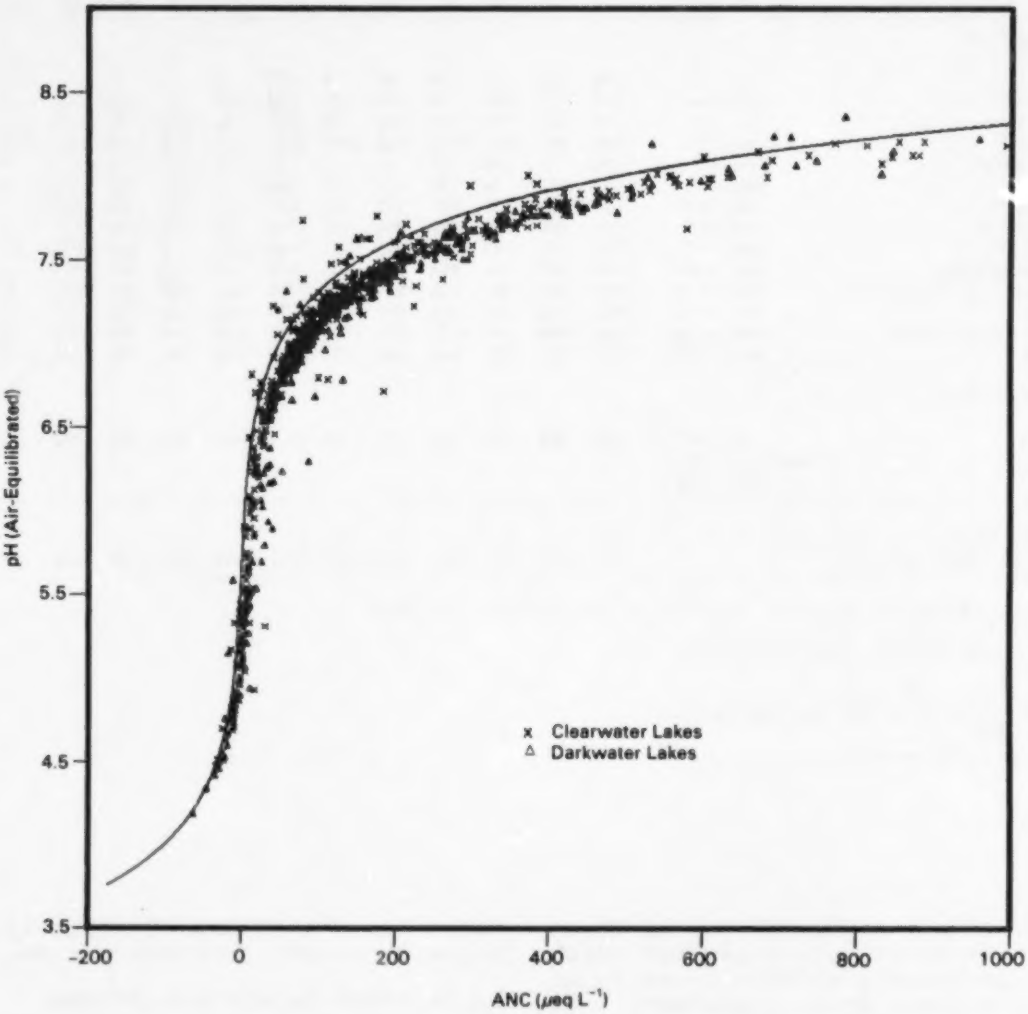
The pH-ANC plot for the Northeast (Figure 5-2) is similar to those produced from previous studies of New York and New England (Blank et al. 1984; Small and Sutton 1986). The pH-ANC relationship for the Upper Midwest (Figure 5-3) was also similar to that observed for the Northeast.

### *5.1.3 Comparison of Lake Sensitivity Indices*

Several investigators have used ANC and pH as single indices of lake sensitivity to acidic deposition. The reference values for these two variables presented in the previous sections are not proposed as discrete levels of sensitivity. However, because population estimates can be made for any reference value found in the distribution, index ANC and pH values proposed by others can be compared.

The sensitivity criteria values, and their definitions, used in other studies have varied considerably. For instance, the Ontario Ministry of the Environment (Anon. 1981) classified lakes as "extremely sensitive" if ANC was less than 40 $\mu$eq $L^{-1}$ or "moderately to highly sensitive" if ANC was 40 to 200 $\mu$eq $L^{-1}$. With respect to long-term acidification, "sensitive" has also been defined as ANC less than 140 $\mu$eq $L^{-1}$ (Galloway 1984), while Altshuller and MacBean (1980) defined it as ANC less than 200 $\mu$eq $L^{-1}$, and Hendrey et al. (1980b) labeled lakes in this category "susceptible". Pfeiffer and Festa (1980) classified lakes as "critical" if ANC was

**Figure 5-6.** pH (air-equilibrated) versus ANC ($\mu eq\ L^{-1}$) for Region 1, Eastern Lake Survey-Phase I. (Clearwater lakes ($\leq 30$ PCU) are shown as x's and darkwater ($>30$ PCU) as triangles. The theoretical curve shown was calculated for 25°C and $10^{-3.5}$ atm $CO_2$.)



less than 10 $\mu eq\ L^{-1}$, "endangered" if ANC was 10 to 50 $\mu eq\ L^{-1}$, or "satisfactory" if ANC was greater than 50 $\mu eq\ L^{-1}$; the same terminology was applied to lakes with pH less than 5.0, 5.0 to 6.0, and greater than 6.0, respectively. Because of the widespread use of sensitivity indices, it is inevitable that the Survey results will be discussed by others in these terms. Table 5-2 presents Survey results using the above indices.

Some authors have indicated that any single variable is a poor measure of lake sensitivity to acidic deposition and proposed multiple factor indices (Table 5-2). Zimmerman and Harvey (1979), for example, considered a lake to be "sensitive" when ANC was less than 300 $\mu eq\ L^{-1}$, pH was less than 6.3, and conductance was less than 30 $\mu S\ cm^{-1}$. The estimates of the number of sensitive lakes are highly dependent on both the variables selected for sensitivity indices and the reference values chosen for each variable.

No simple classification criteria have been proposed to account for the contribution of organic acids to lake acidity or to represent the potential

**Table 5-2. Eastern Lake Survey - Phase I (ELS-I) Population Estimates for Selected Literature Definitions of Sensitivity. (ELS-I Reference Values Are Included for Comparison Only and Are Not Proposed as Sensitivity Classes.)**

| | | Number of Lakes ≤2000 ha by Region and Subregion | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sensitivity Classification | Definition[a] | 1 | 1A | 1B | 1C | 1D | 1E | 2 | 2A | 2B | 2C | 2D | 3A | 3B |
| SINGLE FACTOR | | | | | | | | | | | | | | |
| Critical[b,c] | pH ≤5 | 240 | 128 | 12 | 25 | 66 | 8 | 130 | 0 | 99 | 31 | 0 | 0 | 259 |
| Endangered[b] | pH 5-6 | 676 | 215 | 103 | 166 | 126 | 65 | 688 | 20 | 87 | 380 | 202 | 1 | 427 |
| ELS Reference[c] | pH ≤6 | 916 | 343 | 116 | 191 | 192 | 74 | 818 | 20 | 185 | 411 | 202 | 1 | 687 |
| Satisfactory[b] | pH >6 | 6180 | 947 | 1363 | 1292 | 1126 | 1452 | 7683 | 1437 | 865 | 1069 | 4312 | 257 | 1412 |
| ELS Reference[c] | ANC ≤0 | 326 | 138 | 78 | 35 | 66 | 8 | 148 | 0 | 102 | 45 | 0 | 0 | 463 |
| Critical[b] | ANC ≤10 | 537 | 232 | 92 | 75 | 113 | 25 | 340 | 0 | 136 | 195 | 9 | 0 | 504 |
| Endangered[b] | ANC 10-50 | 827 | 227 | 102 | 187 | 172 | 140 | 972 | 60 | 62 | 418 | 432 | 4 | 238 |
| ELS Reference[c] | ANC ≤50 | 1364 | 459 | 194 | 262 | 284 | 165 | 1312 | 60 | 198 | 612 | 441 | 4 | 742 |
| Satisfactory[b] | ANC >50 | 5732 | 831 | 1285 | 1221 | 1034 | 1361 | 7189 | 1396 | 852 | 868 | 4073 | 254 | 1357 |
| Extreme sensitivity[d] | ANC ≤40 | 1203 | 404 | 181 | 244 | 258 | 116 | 946 | 28 | 192 | 548 | 178 | 2 | 690 |
| Moderate to high sensitivity[d] | ANC 40-200 | 3055 | 505 | 391 | 758 | 497 | 903 | 2572 | 802 | 246 | 291 | 1233 | 86 | 466 |
| Sensitive[e] | ANC ≤100 | 2482 | 607 | 288 | 652 | 420 | 516 | 2174 | 309 | 299 | 738 | 828 | 28 | 1073 |
| Susceptible or senstive[c,f] | ANC ≤200 | 4258 | 909 | 572 | 1002 | 755 | 1020 | 3518 | 830 | 438 | 839 | 1411 | 88 | 1156 |
| Sensitive[g] | ANC ≤140 | 3242 | 756 | 352 | 848 | 552 | 734 | 2855 | 475 | 342 | 781 | 1258 | 43 | 1075 |
| MULTIPLE FACTOR | | | | | | | | | | | | | | |
| Sensitive[h] | pH ≤6.3, conductance ≤30, ANC ≤300, | 858 | 408 | 102 | 229 | 27 | 92 | 1341 | 93 | 250 | 601 | 397 | 3 | 260 |
| ESTIMATED TOTAL NUMBER OF LAKES, ELS-1 | | 7096 | 1290 | 1479 | 1483 | 1318 | 1526 | 8501 | 1457 | 1050 | 1480 | 4515 | 258 | 2098 |

[a] Units for pH are standard units, ANC (μeq $L^{-1}$), conductance (μS $cm^{-1}$), Ca (mg $L^{-1}$).
[b] Pfeiffer and Festa 1980.
[c] Reference values for Eastern Lake Survey-Phase I.
[d] Anon, 1981.
[e] Omernik, unpublished maps.
[f] Altshuller and MacBean 1980; Hendrey et al. 1980.
[g] Galloway 1984.
[h] Zimmerman and Harvey 1979.

sensitivity of darkwater lakes. Organic ligands can complex aluminum, thereby mitigating its toxic effects on fish (Driscoll et al. 1980). However, the response of darkwater systems to acidification is still poorly understood (Gorham et al. 1984). Some additional nonchemical factors are also considered important in determining lake susceptibility to acidification. These factors include: hydrology (Eilers et al. 1983), weathering rates (Schnoor et al. 1983), depth of overburden (Chen et al. 1984), lake sediments (Baker et al. 1985; Cook and Schindler 1983), and land use (Krug and Frink 1983).

In conclusion, any simple definition of sensitivity has inherent limitations that must be recognized. Comparisons of population estimates based on proposed indices demonstrate that conclusions are likely to vary depending on the index used. Until greater progress is made in understanding the processes that control acidification, it is difficult to justify the use of any of these indices except for the purpose of comparing the chemistry of lakes.

## 5.2 Selected Associations Among Chemical Variables

### 5.2.1 Introduction

In addition to addressing the primary objectives of the ELS-I, the Survey data also provided an opportunity to evaluate relationships among variables. Along with pH and ANC, the samples were also analyzed for major anions, major base cations, true color, DOC, silica, aluminum, iron, manganese, and conductivity (Sections 2.5 and 2.6). It is beyond the scope of this report to present an indepth analysis of the relationships among all variables measured during the Survey. However, described here is an overview of some important associations germane to lake acidification processes and hypotheses. Associations do not prove that a causal relationship among variables exists, nor is absence of an association proof that a causal relationship does not exist, but they are useful in formulating or examining relevant hypotheses. Observations that are represented by substituted values (Section 3.4) have been excluded from these analyses.

### *5.2.2 Sulfate*

Many investigators have attempted to draw inferences regarding the extent of acidification by comparing pH, [$Ca^{+2}$ + $Mg^{+2}$] and $SO_4^{-2}$ concentrations (Henriksen 1980). Efforts have also been made to correct the measured sulfate values for sea-salt contributions. This correction permits comparison of "excess" or sea-salt corrected lakewater sulfate to the chemistry of deposition.

The most common procedure for calculating the wet "excess" or sea-salt corrected sulfate has been to relate the $SO_4^{-2}$:$Cl^-$ or $SO_4^{-2}$:$Mg^{+2}$ in sea water to the ratio in lake water. Lake sulfate values are corrected by subtracting the equivalent concentration of sulfate possibly associated with chloride or magnesium. This calculation has been useful in small geographic areas with relatively uniform geologic bedrock and lake types, such as Norway (Henriksen 1980).

Several points should be considered when proposing to make sea-salt corrections to sulfate concentrations:

(1) salt concentrations in rain water derived from oceanic sources may not occur in the same ratios as in sea water (Kroopnick 1977);

(2) sulfate is not a conservative ion in many watersheds and lakes (Johnson and Reuss 1984) and lake sediments (Cook and Schindler 1983);

(3) use of the sea-salt corrections assumes that the ion paired with $SO_4^{-2}$ is derived from sea-salt; i.e., there are no significant sources of $Cl^-$ or $Mg^{+2}$ in the watershed. In cases where natural sources of the paired ions occur, the "corrections" may be misleading; and

(4) the presence of anthropogenic sources of chloride (e.g., road salt), invalidate the correction (Wright 1983).

For these reasons, it was not useful to report sulfate results in the sea-salt corrected form. For example, when sea-salt corrections were applied to several areas, many negative $SO_4^{-2}$ values resulted. Consequently, all sulfate data presented in this report are reported as actual, measured concentrations.

Dickson (1975, 1978) proposed that elevated sulfate concentrations in lakes should also be strongly related to pH and that the highest $SO_4^{-2}$ concentrations should correspond to low pH values. This assumes that $SO_4^{-2}$ is conservative on its path from atmospheric deposition through the watershed and into lakes and that within-lake sulfur cycles are not significant sinks. The results of the Survey do not provide evidence to support this hypothesis. No correlation between pH and $SO_4^{-2}$ was observed in the three subregions with large numbers of low pH lakes: the Adirondacks (1A), the Upper Peninsula of Michigan (2B), and Florida (3B) (Figures 5-7 through 5-9).

It is noteworthy that in the Adirondacks (1A) the concentrations of sulfate described in Figure 5-7 were the highest of these three subregions, approximately double those in the Upper Peninsula of Michigan (2B). This is consistent with the hypothesis that the northeastern lakes have been chemically altered by high levels of atmospheric sulfate deposition, although it does not exclude the possibility that watershed sources contribute disproportionate loadings of $SO_4^{-2}$ among subregions.

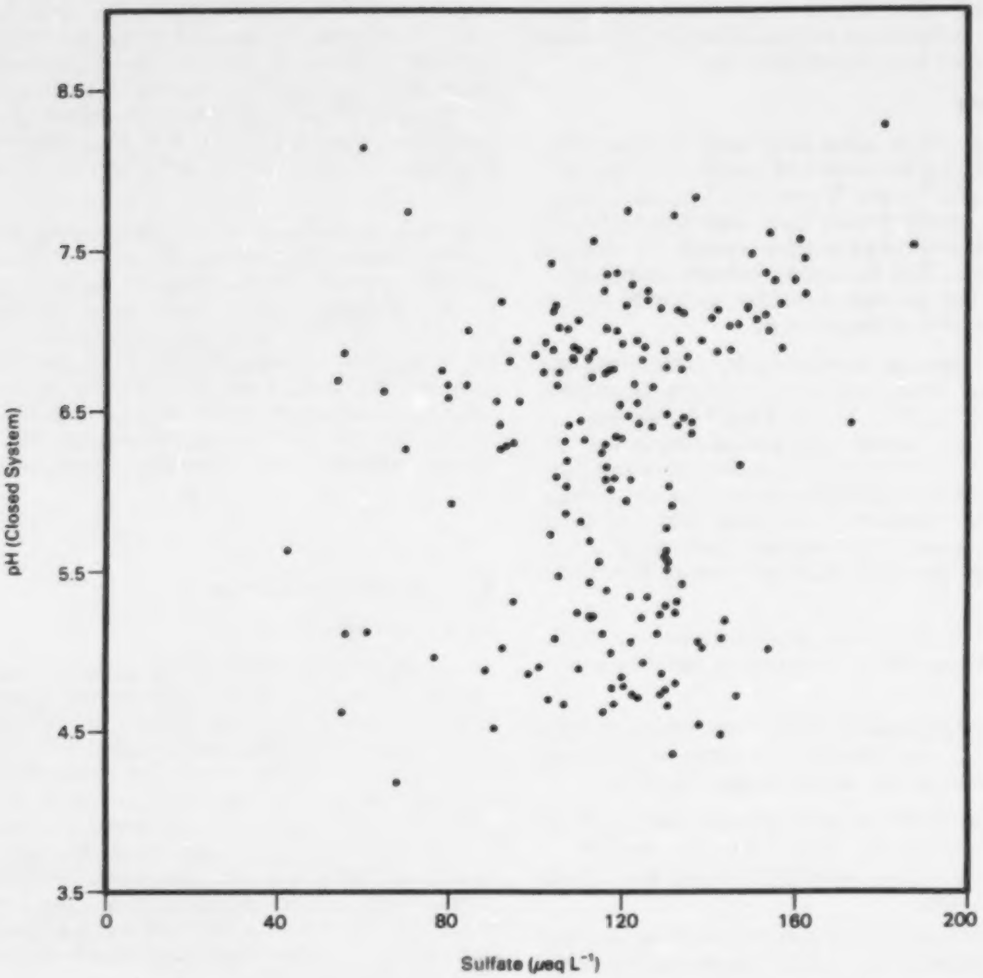
### *5.2.3 Extractable Aluminum*

#### 5.2.3.1 Background

The analysis of chemical forms of aluminum (Al) in natural systems is fraught with sampling and analytical problems (Barnes 1975, Driscoll 1984). In cases where information about ionic forms of Al is desired, analytical differentiation of colloidal, suspended forms from dissolved forms is possible. However, commonly used analytical procedures cannot differentiate among the Al in monomeric dissolved form and any polymeric, colloidal, or crystalline forms in natural waters. Even filtration through 0.1 μm pore-size filters is not adequate for separating and distinguishing dissolved and colloidal Al (Barnes 1975).

The method used in the ELS-I to measure dissolved and readily reactive Al species (extractable aluminum) is based on the operationally defined procedure developed by Barnes (1975). In this method, Al is complexed with 8-hydroxyquinoline and the complex quickly extracted into methyl isobutyl ketone (MIBK) solvent. Equilibrium partitioning of the Al-oxine complex is accomplished in 10 seconds at 20°C if the mixture is shaken vigorously; complete extraction of monomeric Al occurs under these conditions (Barnes 1975). This extractable Al can be referred to as dissolved monomeric Al and occurs as aquo aluminum ($Al^{+3}$), as well as hydroxide, fluoride, sulfate, and organic complexes of Al (Roberson and Hem 1969).

Figure 5-7. pH (closed system) versus sulfate ($\mu$eq L$^{-1}$) for probability sample lakes in Subregion 1A, Eastern Lake Survey-Phase I.

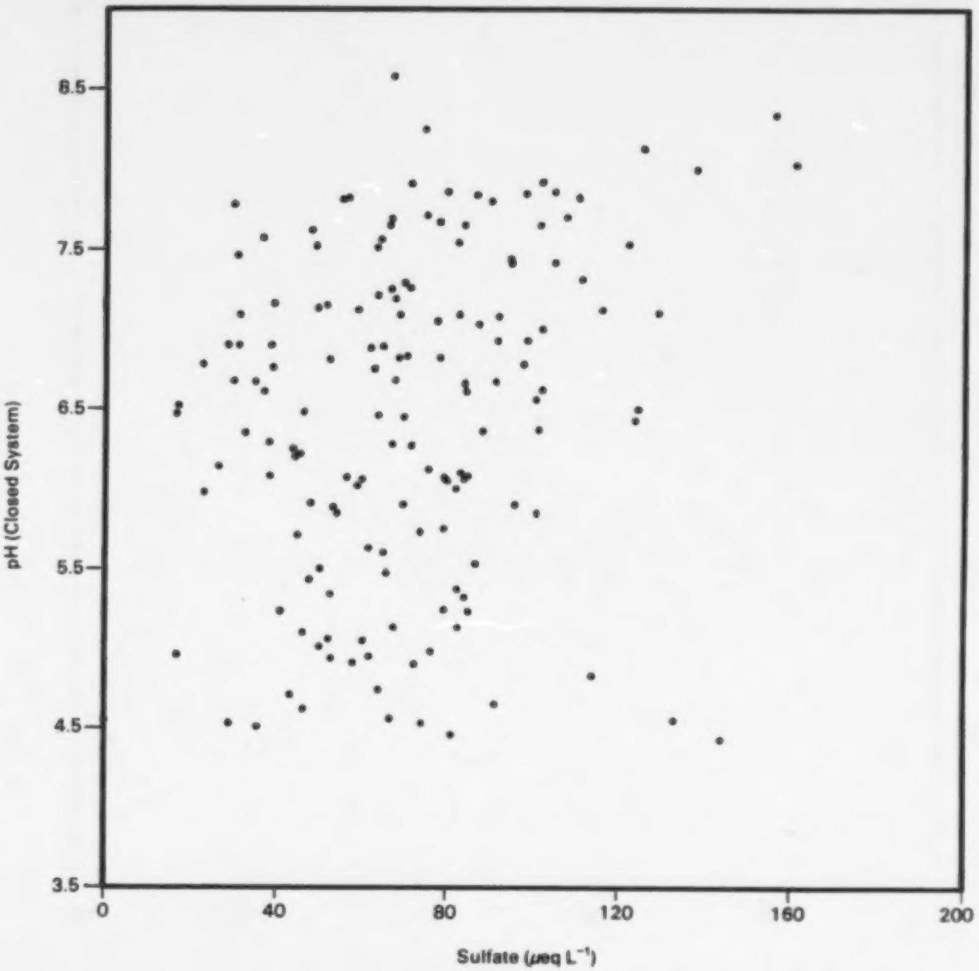


Many of the methods used to measure low concentrations of Al in natural waters involve Al complexation and subsequent analysis of the resulting complex by spectrophotometry or fluorometry. The presence of other complexing metals (Fe and Mn) often limits the use of such methods. Also, the specificity of certain methods depends on the kinetics of the complexation reaction. If the time allowed for complexation is too long, complexation with microcrystalline or adsorbed Al may result in an overestimation of soluble monomeric Al. Therefore, such methods are time-dependent, operationally defined analyses.

The use of filtration to separate particulate forms of Al from the soluble species has received scrutiny (Barnes 1975). Changes in pH can result from $CO_2$ degassing which is enhanced by the turbulence of filtration. Hydrolysis can occur rapidly with pH changes, and hydrolyzed Al adsorbs more readily to filters. In solutions that contain concentrations near or above Al saturation, filtration may cause loss of Al from the soluble phase through precipitation or adsorption. Adsorption of soluble Al to particles present on the filter or to the filter itself may significantly decrease soluble Al concentrations.

Chemical interferences of concern in the ELS-I data include samples containing high concentrations of Fe and/or Mn. Incomplete recovery of monomeric Al occurs when Fe or Mn exceeds 1 mg L$^{-1}$. A total

Figure 5-8. pH (closed system) versus sulfate ($\mu$eq L$^{-1}$) for probability sample lakes in Subregion 2B, Eastern Lake Survey-Phase I.



of 14 lakes had Fe concentrations in excess of 1 mg L$^{-1}$, nine of which were from Region 2. Only three lakes had Mn concentrations above 1 mg L$^{-1}$. Therefore, chemical interference from Fe and Mn likely is insignificant in this study.

### 5.2.3.2 Associations Between Extractable Aluminum and Other Variables

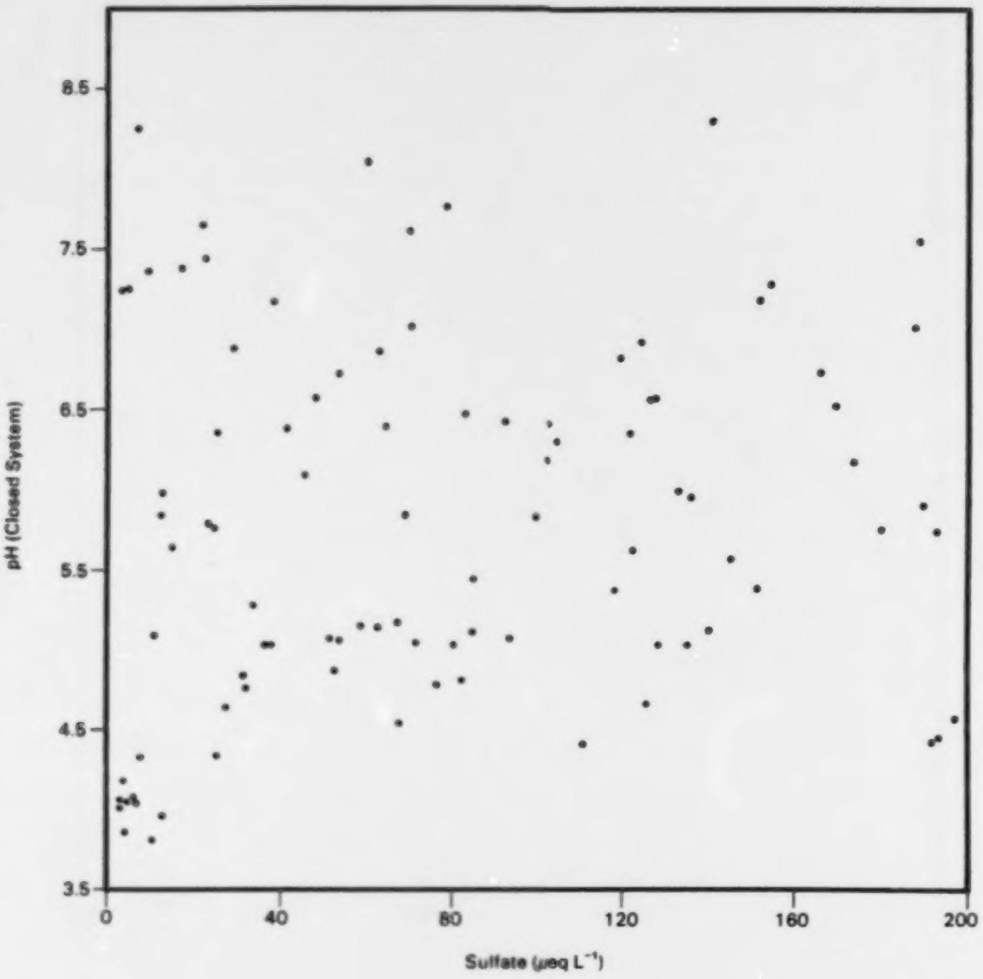
Extractable aluminum concentration is expected to increase with decreasing pH (Cronan and Schofield 1979; Driscoll et al. 1980). Log [extractable Al] was regressed on pH for the Northeast, Upper Midwest, Southern Blue Ridge and Florida (Table 5-3). Figures 5-10 through 5-13 show untransformed values of extractable Al versus pH for each of these areas.

**Table 5-3.** **Regression Statistics for Log [Extractable Al] (Molar, Dependent) versus pH (Independent) for All Regions, Eastern Lake Survey-Phase I**

| Region | n | Slope | Intercept | $r^2$ |
|---|---|---|---|---|
| 1 | 842 | −0.457 | −3.52 | 0.41 |
| 2 | 590 | −0.350 | −4.27 | 0.27 |
| 3A | 106 | −0.277 | −5.18 | 0.12 |
| 3B | 124 | −0.120 | −5.50 | 0.11 |

Extractable Al concentrations are generally greater at low pH values. The relationships were not consistent among the areas: however, the Northeast showed greater values of extractable Al and a steeper increase with decreasing pH than other areas (Table 5-3, Figure 5-10). Lakes in Florida (3B) showed the least increase in Al at low pH values (pH ≤5.0).

Figure 5-9. pH (closed system) versus sulfate ($\mu$eq $L^{-1}$) for probability sample lakes in Subregion 3B, Eastern Lake Survey-Phase I.

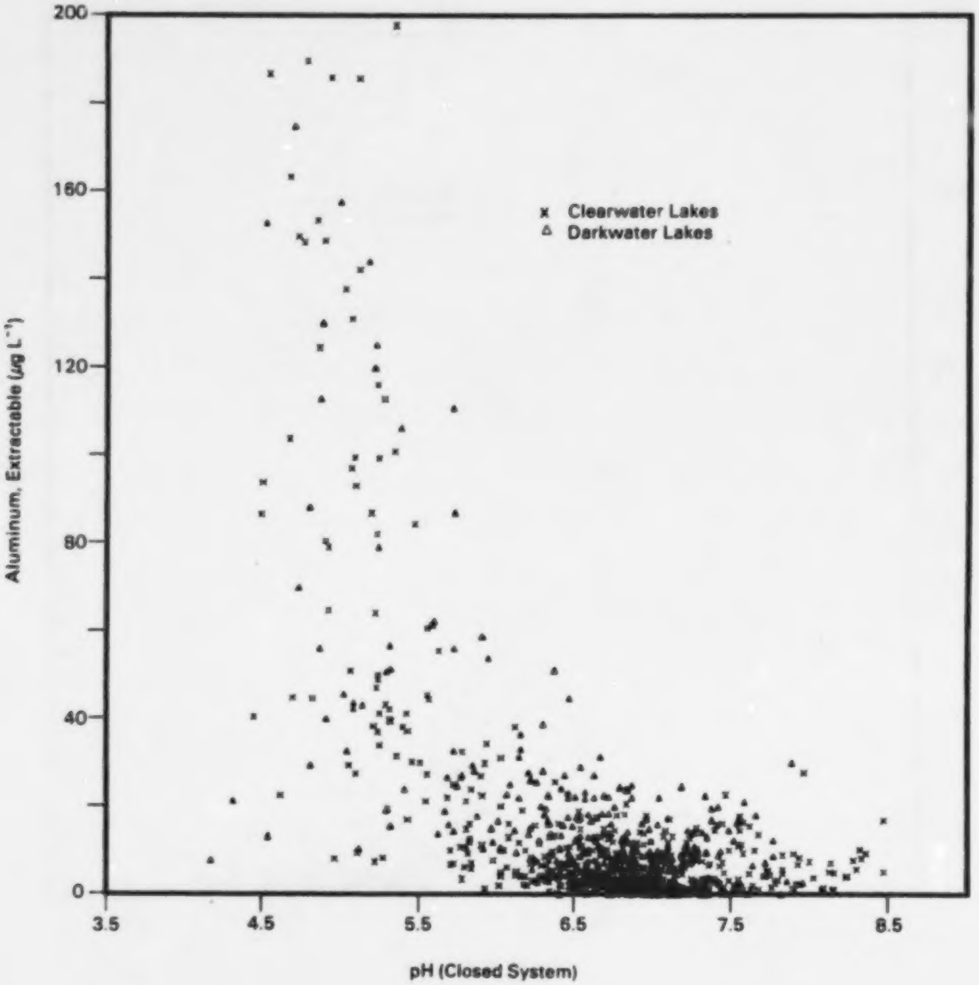


Darkwater lakes and clearwater lakes had similar relationships between extractable Al and pH in the Northeast. In the Upper Midwest, darkwater lakes showed higher extractable Al values for a given pH than did clearwater systems (Figure 5-11). Extractable Al is apparently complexed by organic materials and then extracted by the MIBK. Almost all clearwater lakes with pH ≤5.0 and high extractable Al occurred in the Northeast. Most of these lakes were found in the Adirondacks (1A).

Caution should be used in interpreting the information, since extractable Al analyses are highly variable. The system decision limits, values calculated as the 95th percentile of field blank analyses, were 8 $\mu$g $L^{-1}$ for extractable Al and 30 $\mu$g $L^{-1}$ for total Al. If the system decision limit were used to exclude values near zero, approximately half the data from Regions 1 and 2, and Subregion 3B, and more than 90 percent of the data from Subregion 3A would be excluded from Figures 5-10 through 5-13. Gilliom et al. (1984) suggest that data below detection limits are still useful in detecting data trends. As seen in Figures 5-10 through 5-13 the data with extractable Al values below the system decision limit (<8 $\mu$g $L^{-1}$) demonstrate a similar relationship with pH as those data above the decision limit.

Population estimates of median values of the ratio of extractable Al to total Al ranged from 0.03 in Subregion 3A to 0.22 in Region 2 and Subregion 3B. The range of values for this ratio for all data was

**Figure 5-10.** **Extractable Al ($\mu g\ L^{-1}$) versus pH (closed system) for Region 1, Eastern Lake Survey-Phase I. (Clearwater lakes (≤30 PCU) are shown as x's and darkwater (<30 PCU) as triangles.)**



from 0 to >1, as measured extractable Al exceeded total Al at some sites. This ratio was plotted against DOC for all data and for each subregion but no significant relationships were found.

### *5.2.4 ANC versus Base Cations*

Calcium and magnesium are the primary base cations and bicarbonate is the dominant anion in surface waters. Calcium and magnesium comprise nearly eighty percent of the cations in freshwater on a world average (Livingstone 1963). In many watersheds calcium and magnesium are the primary weathering products. An assumption of carbonic acid weathering is that divalent cations and bicarbonate are produced in equivalent amounts. Consequently, the sum of calcium and magnesium is related directly to alkalinity[4] resulting from carbonic acid weathering reactions. Departures from this linear relationship, to a slope of less than about one and to a negative intercept, have been used as an indication of acidification (Almer et al. 1978). For thirteen reference areas with low sulfate deposition, Henriksen (1980) found a relationship between non-marine $[CA^{+2} + Mg^{+2}]$ and alkalinity where $ALK = 14 + 0.93\ [Ca^{*} + Mg^{*}]$, where $Ca^{*}$ and $Mg^{*}$ represent sea-salt corrected concentrations.

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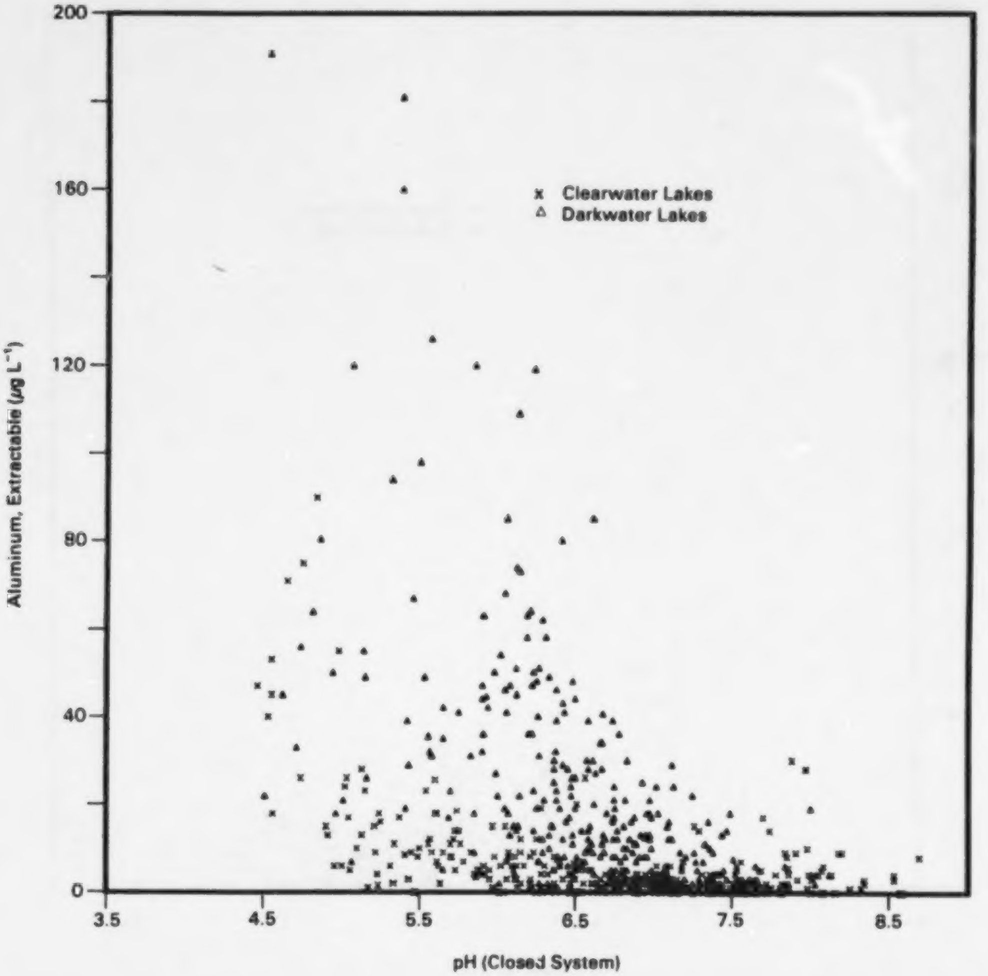
[4] For purposes of this analysis, ANC is treated interchangeably with alkalinity and bicarbonate. Distinction between these terms can be found in Kramer (1984).

**Figure 5-11.** **Extractable Al ($\mu g\ L^{-1}$) versus pH (closed system) for Region 2, Eastern Lake Survey-Phase I. (Clearwater lakes ($\leq$30 PCU) are shown as x's and darkwater (<30 PCU) as triangles.)**

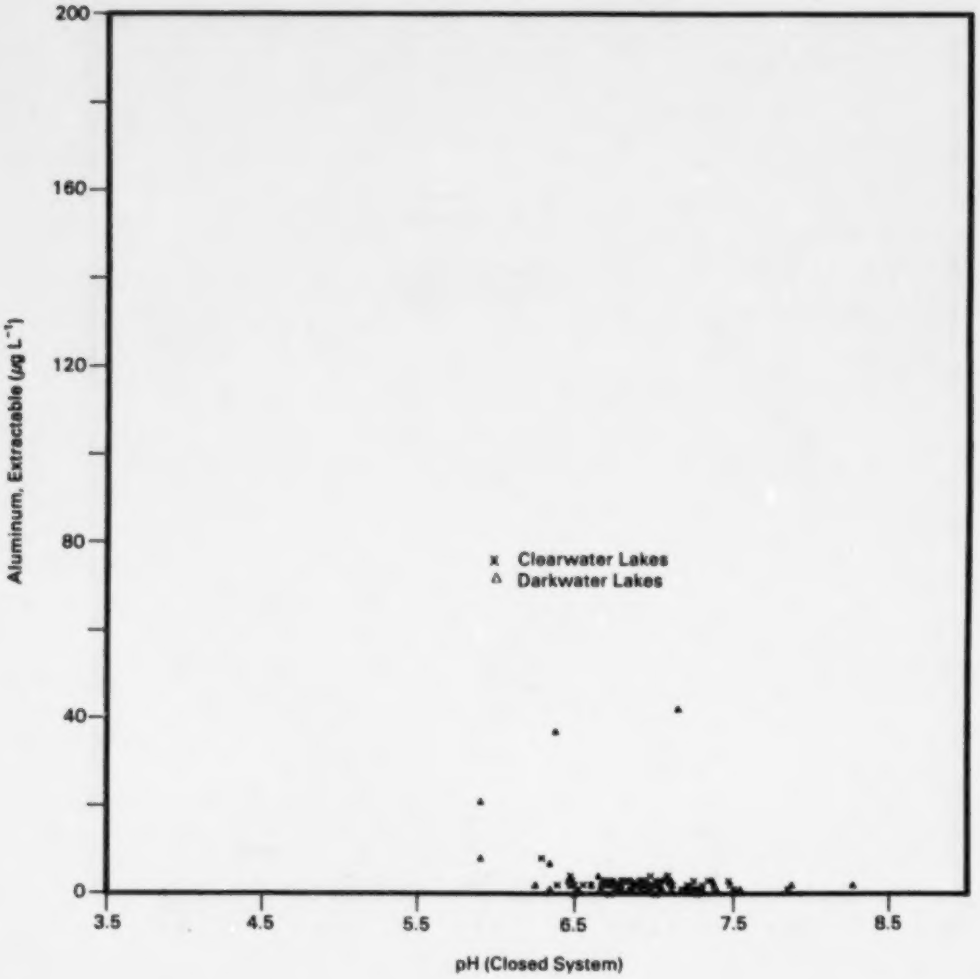


Henriksen (1980) developed a predictor nomograph based on the relationships between ANC and [Ca + Mg] using regressions from Norwegian data between rainwater sulfate and lakewater sulfate, and those between lakewater pH and lakewater [$Ca^{+2}$ + $Mg^{+2}$]. The nomograph has been used to infer acidification from the deficit of ALK relative to concentrations of [$Ca^{+2}$ + $Mg^{+2}$]. It has also been used to estimate steady-state alkalinity assuming an increase in the acidity of precipitation. One of the components of the nomograph is the regression of [$Ca^{+2}$ + $Mg^{+2}$] on ALK. When forced through the origin, this yields ALK = 0.91 [$CA^{*}$ + $Mg^{*}$].

Examples of the difficulties encountered when applying the nomograph without modification to North America are found in Haines and Akielaszek (1983) and Church and Galloway (1984), who attempted to apply the model to New England and the Adirondacks, respectively. One of the difficulties encountered by Wright (1983) was in estimating background sulfate concentrations for each region of North America for use in the empirical model of Henriksen.

It was not possible to apply the predictor nomograph without calibration to the results of the Survey because many of the assumptions necessary for its application were not met. For example, lakes with significant organic anion concentrations (usually indicated by high DOC) have anion deficits, and may also have increased concentrations of base cations due to chelation by organic complexes (Henriksen 1979, Oliver et al. 1983). Consequently,

Figure 5-12. Extractable Al ($\mu g\ L^{-1}$) versus pH (closed system) for Subregion 3A, Eastern Lake Survey-Phase I. (Clearwater lakes ($\leq 30$ PCU) are shown as x's and darkwater ($<30$ PCU) as triangles.)

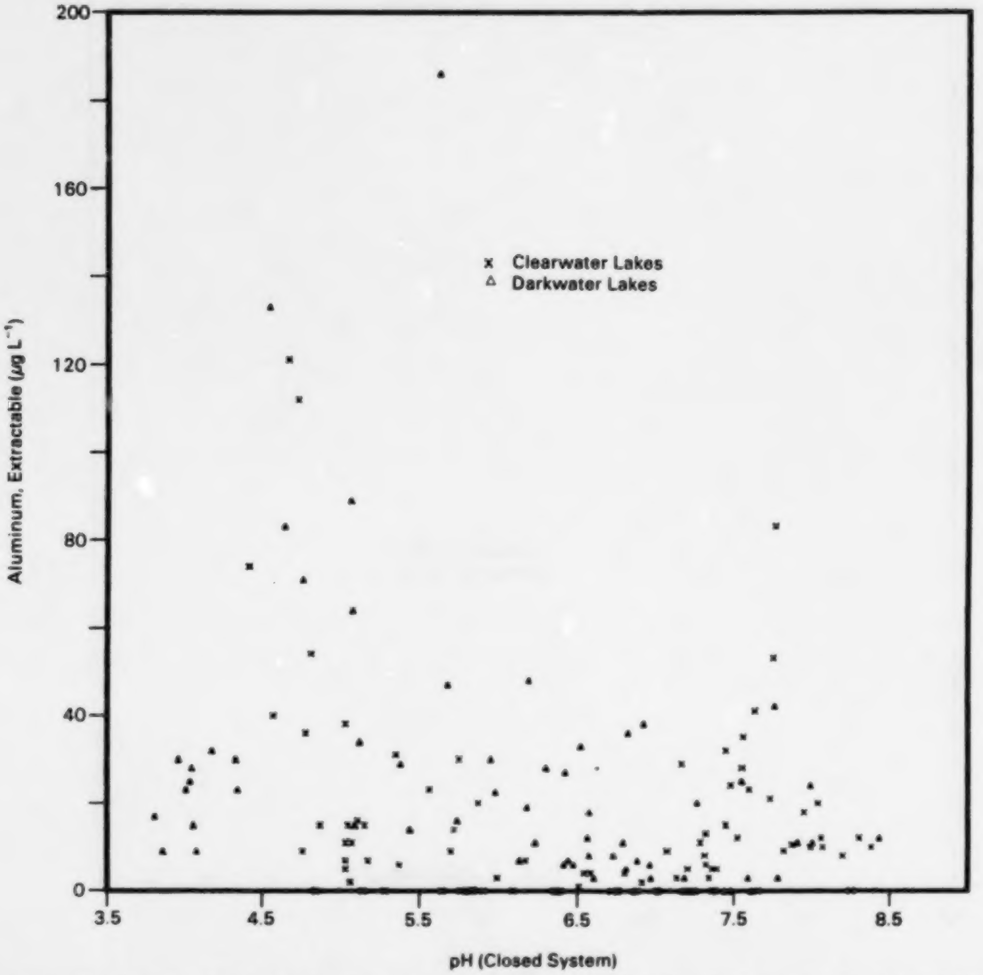


high DOC lakes have been excluded from previous applications of the nomograph. The leaching of base cations from soils increases under conditions of mineral acid weathering, but the increase can only be approximated (Henriksen 1982; Wright 1983). Differences in bedrock, geology, hydrology, in-lake processes and sources of sulfur and other ions vary from area to area, likely requiring recalibration to each area of application.

None of the areas sampled in ELS-I yielded significant relationships between sulfate concentrations and $[Ca^{+2} + Mg^{+2}]$. A large degree of scatter in this relationship was observed in all subregions, with high sulfate values found at both low and high concentrations of base cations. Wright (1983) also observed no relationship between $SO_4^{-2}$ and $[Ca^{+2} + Mg^{+2}]$ for three reference areas in North America using sea-salt corrections and concluded that background sulfate concentrations were regional in nature. Background excess sulfate was estimated at 26 to 41 $\mu eq\ L^{-1}$, with somewhat higher concentrations in the Upper Midwest (Wright 1983).

The relationship between base cations and ANC (such as ANC versus $[Ca^{+2} + Mg^{+2}]$) is useful in illustrating differences between weathering products and regimes in the subregions sampled. A slight deficit of ANC relative to base cations $[Ca^{+2} + Mg^{+2}]$ (intercept between $-7$ and $-27$ $\mu eq\ L^{-1}$) has been observed in several reference areas

Figure 5-13. Extractable Al ($\mu g\ L^{-1}$) versus pH (closed system) for Subregion 3B, Eastern Lake Survey-Phase I. (Clearwater lakes ($\leq 30$ PCU) are shown as x's and darkwater ($<30$ PCU) as triangles.)



where weathering is due principally to carbonic acid (Henriksen 1980; Liaw 1982; Wright 1983). Intercepts more negative than $-27\ \mu eq\ L^{-1}$ have been regarded as evidence of some mineral acid or noncarbonic acid weathering (Henriksen 1980). Thus, deficits $>-27\ \mu eq\ L^{-1}$ should be proportional to the concentration of sulfate (Kramer and Tessier 1982).

Henriksen (1980) calculated a slope of 0.93 for lakes in areas not receiving acidic deposition. Values of slope $<0.9$ have been attributed to increases in base cation weathering rates, also due to the presence of mineral acids. In this case, less ANC is present than would be expected on the basis of the concentrations of $[Ca^{+2} + Mg^{+2}]$.

Table 5-4 gives the regression statistics for the relationship of ANC versus $[Ca^{+2} + Mg^{+2}]$ by subregion for ELS-I. Statistics are given for ANC as the dependent variable, with an upper limit of ANC and $[Ca^{+2} + Mg^{+2}]$ established as $\leq 200\ \mu eq\ L^{-1}$. In all cases, comparisons between all lakes and clearwater lakes are given. Clearwater lakes are presented separately because of the potential chelation by organic complexes of $Ca^{+2}$ and $Mg^{+2}$ in darkwater lakes and the contribution of organic acids. Measured values of $[Ca^{+2} + Mg^{+2}]$ in darkwater lakes can be greater than ionic values due to this complexation.

In all of the subregions in the Northeast, the intercepts of ANC versus $[Ca^{+2} + Mg^{+2}]$ for clearwater lakes were negative, ranging from $-72.2$ in Southern New England (1D) to $-46.3$ in Maine (1E). Slopes for clearwater lakes (true color $\leq 30$ PCU)

**Table 5-4.** **Regression Statistics for ANC (Dependent) versus Base Cations* (Independent) by Subregion, Eastern Lake Survey-Phase I**

| Subregion | n | Regression | Lakes | Intercept | Slope | $r^2$ |
|---|---|---|---|---|---|---|
| 1A | 114 | ANC vs. [Ca+Mg] | All | −57.0 | 0.723 | 0.691 |
| | 82 | ANC vs. [Ca+Mg] | Clearwater | −51.6 | 0.673 | 0.635 |
| | 81 | ANC vs. [Ca+Mg+Na+K] | Clearwater | −56.8 | 0.546 | 0.738 |
| 1B | 44 | ANC vs. [Ca+Mg] | All | −53.7 | 0.547 | 0.404 |
| | 32 | ANC vs. [Ca+Mg] | Clearwater | −46.4 | 0.465 | 0.386 |
| | 32 | ANC vs. [Ca+Mg+Na+K] | Clearwater | 6.3 | 0.060 | 0.069 |
| 1C | 123 | ANC vs. [Ca+Mg] | All | −52.9 | 0.914 | 0.701 |
| | 86 | ANC vs. [Ca+Mg] | Clearwater | −58.2 | 0.977 | 0.725 |
| | 86 | ANC vs. [Ca+Mg+Na+K] | Clearwater | 3.5 | 0.280 | 0.375 |
| 1D | 47 | ANC vs. [Ca+Mg] | All | −60.0 | 0.756 | 0.401 |
| | 38 | ANC vs. [Ca+Mg] | Clearwater | −72.2 | 0.859 | 0.440 |
| | 38 | ANC vs. [Ca+Mg+Na+K] | Clearwater | 44.5 | −0.001 | 0.000 |
| 1E | 93 | ANC vs. [Ca+Mg] | All | −45.7 | 0.967 | 0.740 |
| | 67 | ANC vs. [Ca+Mg] | Clearwater | −46.3 | 0.987 | 0.742 |
| | 67 | ANC vs. [Ca+Mg+Na+K] | Clearwater | −1.4 | 0.345 | 0.295 |
| 2A | 71 | ANC vs. [Ca+Mg] | All | −39.8 | 0.864 | 0.667 |
| | 16 | ANC vs. [Ca+Mg] | Clearwater | −41.3 | 0.944 | 0.708 |
| | 16 | ANC vs. [Ca+Mg+Na+K] | Clearwater | −74.9 | 0.906 | 0.834 |
| 2B | 83 | ANC vs. [Ca+Mg] | All | −46.9 | 0.793 | 0.662 |
| | 48 | ANC vs. [Ca+Mg] | Clearwater | −57.9 | 0.971 | 0.717 |
| | 48 | ANC vs. [Ca+Mg+Na+K] | Clearwater | −69.1 | 0.878 | 0.718 |
| 2C | 114 | ANC vs. [Ca+Mg] | All | −40.8 | 0.760 | 0.576 |
| | 83 | ANC vs. [Ca+Mg] | Clearwater | −41.3 | 0.775 | 0.572 |
| | 83 | ANC vs. [Ca+Mg+Na+K] | Clearwater | −20.8 | 0.411 | 0.399 |
| 2D | 84 | ANC vs. [Ca+Mg] | All | −42.1 | .995 | 0.677 |
| | 38 | ANC vs. [Ca+Mg] | Clearwater | −35.5 | 0.892 | 0.737 |
| | 38 | ANC vs. [Ca+Mg+Na+K] | Clearwater | −33.0 | 0.668 | 0.699 |
| 3A | 58 | ANC vs. [Ca+Mg] | All | 24.6 | 0.938 | 0.677 |
| | 35 | ANC vs. [Ca+Mg] | Clearwater | 37.4 | 0.846 | 0.724 |
| | 35 | ANC vs. [Ca+Mg+Na+K] | Clearwater | −0.4 | 0.713 | 0.868 |
| 3B | 55 | ANC vs. [Ca+Mg] | All | −86.9 | 0.597 | 0.215 |
| | 37 | ANC vs. [Ca+Mg] | Clearwater | −30.9 | 0.191 | 0.117 |
| | 37 | ANC vs. [Ca+Mg+Na+K] | Clearwater | −12.1 | −0.006 | 0.001 |

*Not corrected fo sea-salt contributions.

ranged from 0.465 in the Poconos/Catskills (1B) to 0.987 in Maine (1E). In a survey of lakes in New England (primarily the area represented by Subregions 1C, 1D and 1E), Haines and Akielaszek (1983) found a relationship of ANC = −55 + [Ca* + Mg*], where calcium and magnesium had been corrected for sea-salt contributions.

The sum of base cations [$Ca^{+2}$ + $Mg^{+2}$ + $Na^{+}$ + $K^{+}$] was regressed on ANC for clearwater lakes. In the Northeast, with the exception of the Adirondacks (1A), the addition of $Na^{+}$ and $K^{+}$ produced intercepts that were near zero or were positive. In all areas the slopes decreased and $r^2$ values were much lower for all areas except the Adirondacks (1A). This indicates that on a subregional basis the [$Na^{+}$ + $K^{+}$] is in association with anions other than $HCO_3^-$, such as $Cl^-$ and $SO_4^{-2}$, and most probably is derived from sea spray or road salt contamination.

In the Upper Midwest, values of the intercept of ANC versus [$Ca^{+2}$ + $Mg^{+2}$] ranged from −57.9 in the Upper Peninsula of Michigan (2B) to −35.5 in the Upper Great Lakes Area (2D). Only the slope for Subregion 2C varied from the range of reference values given by Henriksen (1980) and, with the exception of Subregion 2B, the subregions in Region 2 had less negative intercepts than the subregions in the Northeast.

Also in contrast to the Northeast, when all major cations were considered, the relationships remained similar because of a lack of influence by sea-salt. The intercepts were more negative in Subregions 2A and 2B, with a slight decrease in slope. In Subregions 2C and 2D, the intercepts were less negative, also with a decrease in slope.

For the Southern Blue Ridge (3A), the intercepts of $[Ca^{+2} + Mg^{+2} + Na^{+} + K^{+}]$ versus ANC for both clearwater and all lakes were positive due to the important contribution of sodium and potassium to the sum of base cations. The slopes were 0.846 and 0.938 for clearwater and all lakes, respectively. Considering all major cations forced the regression through the origin due to the high watershed sources of sodium and potassium.

In Florida (3B), the relationship of ANC versus $[Ca^{+2} + Mg^{+2}]$ showed poor fit for all lakes and also for clearwater lakes. This is further evidence that Florida (3B) lakes represent a unique set of chemical conditions compared to lakes sampled in other areas. Similar poor fit was observed by Wright (1983). After noting the unusual chemical composition and unexplained high variance in sulfate concentrations in lakes from the Trail Ridge and Highland Ridge areas, lakes in Florida were not analyzed further (Wright 1983). If all major cations are used, there is no relationship with ANC for lakes in Florida (3B). This is related to the major contribution of sodium to the total of base cations, and high equivalents of potassium, chloride and sulfate.

### *5.2.5 Major Cations and Anions*

For many lakes, bicarbonate and calcium are the principal ions and much can be learned by evaluating the concentrations of these ions. However, a more thorough understanding of lake chemistry can be achieved by evaluating all major anions and cations collectively. Comparison of major anions and cations is a common technique for analyzing lake chemistry data. An assumption in the use of these comparisons is that all major anions and cations have been measured.

#### 5.2.5.1 Individual Example Lakes

The strength and focus of the Survey design is that it allows populations of lakes to be described. However, it can be useful to evaluate differences in lake chemistry among subregions by examining the chemistry of individual lakes that are "typical" of a population. No lake can be representative of other lakes with respect to all chemical attributes, but the relative concentrations of anions and cations observed among individual lakes can be used to highlight features of many similar lakes among subregions.

A direct way of examining associations among anions and cations is with ion bar charts. Figures 5-14 and 5-15 show the cationic and anionic composition of a lake selected from each of the eleven subregions. Lakes were selected on a basis of their ANC and DOC values to standardize the presentation such that each lake in the aforementioned figures has ANC and DOC concentrations approximately equal to the $Q_1$ (20th percentile) values for the respective subregion (Section 4.7, Table 4-25). The ionic concentrations of cations and anions in each lake are expressed as percentages of the total ionic concentration on the Y axis. The total ionic concentration is shown adjacent to each lake. Ions measured at less than 5 $\mu eq\ L^{-1}$ ($Fe^{+3}$, $Mn^{+2}$, $Al^{+3}$, $NH_4^{+}$, $NO_3^{-}$, $F^{-}$) are not included in this comparison. Organic anions were not measured directly, but their contribution to the ionic composition of the lake can be inferred by examining the anion deficit (sum of cations–sum of anions).

Figure 5-14 shows the cations and anions for Whitney Lake, New York, in Subregion 1A. Cations ($Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, and $K^{+}$)[5] are shown by the top bar; anions ($HCO_3^{-}$, $SO_4^{-2}$, and $Cl^{-}$) by the bottom bar. Calcium is the predominant cation, followed in order of percent ionic concentration by magnesium, sodium, potassium, and hydrogen ion (not shown on figure). Sulfate is the major anion, with only small percentages of bicarbonate (4.7%) and chloride (2.7%) present. The sums of cations and anions show close agreement and the total ionic concentration for this lake in Subregion 1A is lowest among the five lakes shown for Region 1.

As the figure demonstrates, Hiawatha Lake in Subregion 1B is considerably higher in total ionic concentration than Whitney Lake (1A). Lake Hiawatha exhibited a 4 percent anion deficit, equal to 21 $\mu eq\ L^{-1}$, and showed a moderate percentage of sodium (11.9%) and bicarbonate (15.9%). The total ionic concentration and the relative percentages of ions of Pemigewasset Lake in Subregion 1C are very similar to Quabbin Reservoir in Subregion 1D, which are primarily attributed to high concentrations of sodium and chloride. Like Hiawatha Lake, Peabody Pond in Subregion 1E also shows a 4.4 percent (16 $\mu eq\ L^{-1}$) anion deficit.

All four example lakes shown for Region 2 (Figure 5-15) exhibit some degree of anion deficit, ranging from 5.4 percent (11 $\mu eq\ L^{-1}$) in Brown Lake, Wisconsin, to 9.9 percent (34 $\mu eq\ L^{-1}$) in Louis Lake, Minnesota. This is consistent with population estimates showing high first quintile ($Q_1$) values of DOC for Region 2. Brown Lake, Wisconsin (Subregion 2C) is noteworthy because of the low ionic concentration of 205 $\mu eq\ L^{-1}$ and contrasts sharply with the high ionic concentration in Blue Lake, Florida. Both Estes Lake (2B) and Brown Lake (2C) are most similar in ionic composition to Whitney Lake (1A), but differ in that the Region 2 example lakes

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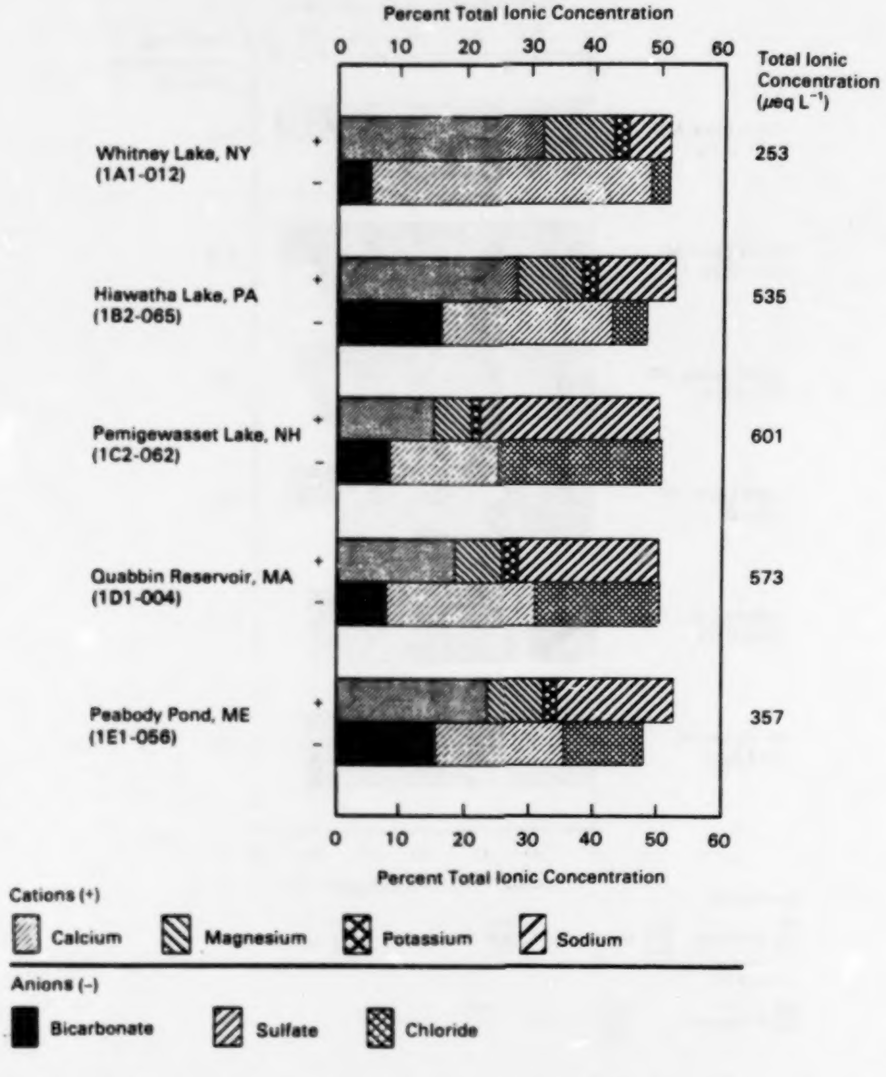
[5] Charges were assigned to cations by converting the units reported by the laboratory (in mg $L^{-1}$) to equivalents (Hillman et al. 1986).

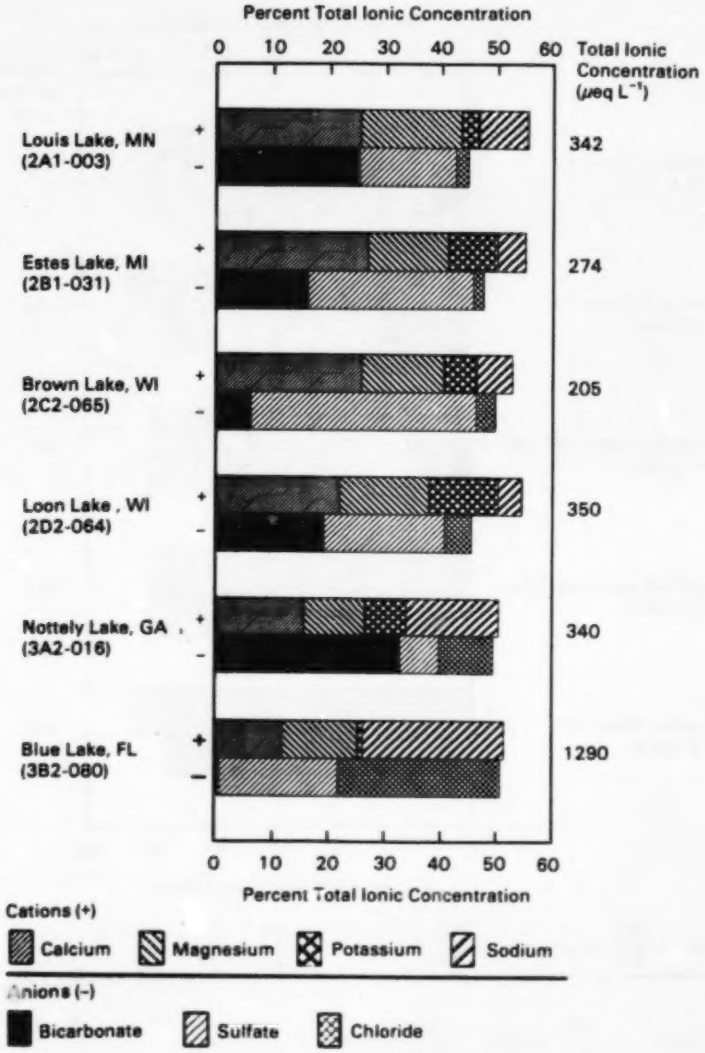
Figure 5-14. Ionic composition of selected lakes from Region 1, Eastern Lake Survey-Phase I.



show an anion deficit and a higher percentage of potassium. Loon Lake (2D) differs from the other lakes shown here in the high proportion of potassium. This high potassium concentration is not representative of lakes in Subregion 2D ($Q_1$ = 15 $\mu$eq L$^{-1}$K) and illustrates that "typical" lakes based on some variables may not be typical with respect to other variables.

Nottely Lake, Georgia, is typical of lakes in 3A in exhibiting close agreement between the sums of major ions and cations. This lake and many others in the Southern Blue Ridge (3A) show a high percentage of sodium. Nottely Lake contains the lowest percentage of sulfate and the highest percentage of bicarbonate of all example lakes in Figures 5-14 and 5-15. Blue Lake in Florida (3B) (Figure 5-15) shows a high total ionic concentration relative to the other example lakes. This is attributed to the high concentrations of sodium and chloride. Unlike the other example lakes in which the concentration of sodium exceeded chloride, chloride in Blue Lake and Loon Lake (2D) exceeded sodium. Because of the great heterogeneity in chemistry among lakes in Subregion 3B (Section 6.3), it is also likely that an example lake could have been selected with ANC and

**Figure 5-15.** Ionic composition of selected lakes from Region 2 and Subregions 3A and 3B, Eastern Lake Survey-Phase I.



DOC values similar to those of Blue Lake, but with substantially lower concentrations of sodium and chloride. Blue Lake, Florida, also differs from other example lakes in the low concentration of bicarbonate ion and low pH (5.35).

### 5.2.5.2 Order of Major Ions

The relative importance of major cations and anions among the subregions is summarized in Table 5-5. The order of the ions is presented based on population estimates for the $Q_1$ (20th percentile) value and the median concentration. Previous sections have described patterns of $SO_4^{-2}$ and ANC; this section focuses on relationships of other major ions.

Other studies of the chemical composition of lakes and rivers have observed the following order of major cation concentrations: $Ca^{+2} > Mg^{+2} > Na^{+} > K^{+}$ (Livingstone 1963; Hutchinson 1957; Rodhe 1949; Gorham 1955). Six of the eleven ELS-I subregions showed a rank order of cations consistent with the above pattern based on the $Q_1$ concentrations and only five subregions showed this order based on the concentrations at median values.

**Table 5-5. Order of Major Cations and Anions Based on Population Estimates of Concentrations at the 20th Percentile ($Q_1$) and Median Values, Eastern Lake Survey-Phase I**

| | Cations | | Anions | |
|---|---|---|---|---|
| Subregion | $Q_1$ | M | $Q_1$ | M |
| 1A | $Ca > Mg \approx Na > K$ | $Ca > Mg > Na > K$ | $SO_4 > Cl \approx HCO_3$ | $SO_4 > HCO_3 > Cl$ |
| 1B | $Ca > Mg > Na > K$ | $Ca > Na \approx Mg > K$ | $SO_4 > HCO_3 > Cl$ | $HCO_3 > SO_4 > Cl$ |
| 1C | $Ca > Na > Mg > K$ | $Ca > Na > Mg > K$ | $SO_4 > HCO_3 > Cl$ | $HCO_3 \approx SO_4 \geq Cl$ |
| 1D | $Na > Ca > Mg > K$ | $Na > Ca > Mg > K$ | $Cl > SO_4 > HCO_3$ | $Cl > SO_4 \approx HCO_3$ |
| 1E | $Ca > Na \approx Mg > K$ | $Ca > Na \approx Mg > K$ | $HCO_3 \approx SO_4 > Cl$ | $HCO_3 > SO_4 > Cl$ |
| 2A | $Ca > Mg > Na > K$ | $Ca > Mg > Na > K$ | $HCO_3 > SO_4 > Cl$ | $HCO_3 > SO_4 > Cl$ |
| 2B | $Ca > Mg > Na \approx K$ | $Ca > Mg > Na > K$ | $SO_4 > HCO_3 > Cl$ | $HCO_3 > SO_4 > Cl$ |
| 2C | $Ca > Mg > K \approx Na$ | $Ca > Mg > Na > K$ | $SO_4 > HCO_3 \approx Cl$ | $HCO_3 > SO_4 > Cl$ |
| 2D | $Ca > Mg > Na \approx K$ | $Ca > Mg > Na > K$ | $HCO_3 > SO_4 > Cl$ | $HCO_3 > SO_4 > Cl$ |
| 3A | $Ca \approx Na > Mg > K$ | $Ca \approx Na > Mg > K$ | $HCO_3 > Cl \approx SO_4$ | $HCO_3 > Cl > SO_4$ |
| 3B | $Na > Mg \approx Ca > K$ | $Ca > Na > Mg > K$ | $Cl > SO_4 > HCO_3$ | $Cl > SO_4 > HCO_3$ |

The rank order of anions based on median values for seven of the subregions is $HCO_3^- > SO_4^{-2} > Cl^-$. Only in Subregion 1A is sulfate the dominant anion at median values. Chloride is the major anion in Subregions 1D and 3B, consistent with the high sodium values in these subregions. Sulfate is the least abundant anion in Subregion 3A. The deviation of major cations from the expected order is attributed largely to the relatively high concentration of sodium in Subregions 1D and 3B, and to a lesser degree in Subregions 1B, 1C, 1E and 3A. The concentration of sodium in lakes is of interest because of the potential acidifying influence of neutral salts (Rosenqvist 1978, Krug et al. 1984). For example, perched coastal lakes in Australia receiving large contributions of sea-salt have been shown to be acidic (Bayly 1964). However, Figure 4-11 (Section 4.5.1.2) reveals that, with the exception of the Cape Cod area, no concentrations of acidic lakes occur near the coast.

The order of major anions represented on Table 5-5 may be somewhat misleading because not all anions are measured in the analytical process, which is apparent from the large anion deficits in some lakes. By including anion deficit as an undefined collection of anions (presumably composed primarily of humic and fulvic acids), a different pattern emerges (Table 5-6). At the 20th percentile of anion concentrations, the concentration of unmeasured anions becomes second in importance in Subregions 2A, 2C and 2D. In Subregions 2A and 2D, this is attributed to the high concentration of the unmeasured anions, whereas in Subregion 2C, this results from the overall low ionic concentrations. Over 20 percent of the lakes in Subregions 1A, 1B, 1D and 3A have no unmeasured anions and no subregions in Region 1 show appreciable influence of unmeasured anions at $Q_1$ values. At median concentrations, all subregions except 1D and 3A show the presence of unmeasured anions and illustrate the importance of considering unmeasured anions when evaluating lake chemistry for some populations of lakes.

**Table 5-6. Order of Major Anions by Subregion Based on the 20th Percentile ($Q_1$) and Median Concentrations Including $A^-$ as Unmeasured Anions,* Eastern Lake Survey-Phase I.**

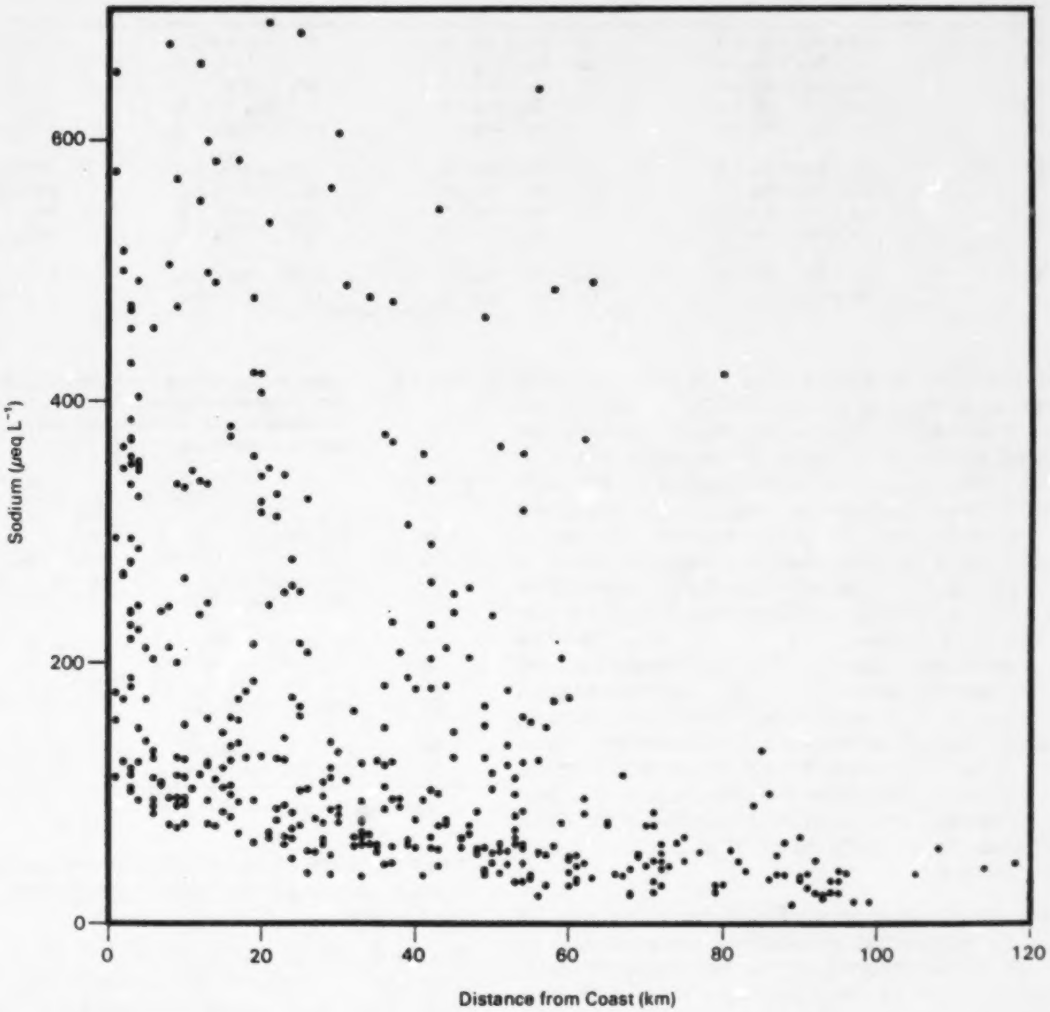
| Subregion | $Q_1$ | Median |
|---|---|---|
| 1A | $SO_4 > Cl \approx HCO_3$ | $SO_4 > HCO_3 > A^- > Cl$ |
| 1B | $SO_4 > HCO_3 > Cl$ | $HCO_3 > SO_4 > Cl > A^-$ |
| 1C | $SO_4 > HCO_3 > Cl > A^-$ | $HCO_3 \approx SO_4 > Cl > A^-$ |
| 1D | $Cl > SO_4 > HCO_3$ | $Cl > SO_4 \approx HCO_3$ |
| 1E | $HCO_3 \approx SO_4 > A^- \approx Cl$ | $HCO_3 > SO_4 > A^- \approx Cl$ |
| 2A | $HCO_3 > A^- \approx SO_4 > Cl$ | $HCO_3 > A^- > SO_4 > Cl$ |
| 2B | $SO_4 > HCO_3 \approx A^- > Cl$ | $HCO_3 > SO_4 > A^- > Cl$ |
| 2C | $SO_4 > A^- \approx HCO_3 \approx Cl$ | $HCO_3 > SO_4 > A^- > Cl$ |
| 2D | $HCO_3 > A^- \approx SO_4 > Cl$ | $HCO_3 > A^- > SO_4 > Cl$ |
| 3A | $HCO_3 > Cl \approx SO_4$ | $HCO_3 > Cl > SO_4$ |
| 3B | $Cl > SO_4 > A^- \approx HCO_3$ | $Cl > A^- \approx SO_4 > HCO_3$ |

*$A^-$ not shown if equal to zero

The moderate to high sodium (and chloride) concentrations in Region 1 can be attributed, in part, to contribution from sea-salt. Figure 5-16 shows the concentration of sodium in lakes of Region 1 as a function of distance from the coast. Distance from the coast is not a totally satisfactory measure of potential contribution from marine sources because other factors such as prevailing winds and topography affect the transport of sea spray. The sodium concentration decreases inland from the coast, approaching minimum values for Region 1 at approximately 60 km from the coast for sites not affected by road salt.

At least some of the lakes with high concentrations of sodium in these lakes can be attributed to road salt used as a deicing agent. Six states within Region 1, where approximately 1.8 million tons of sodium chloride were applied during the winter of

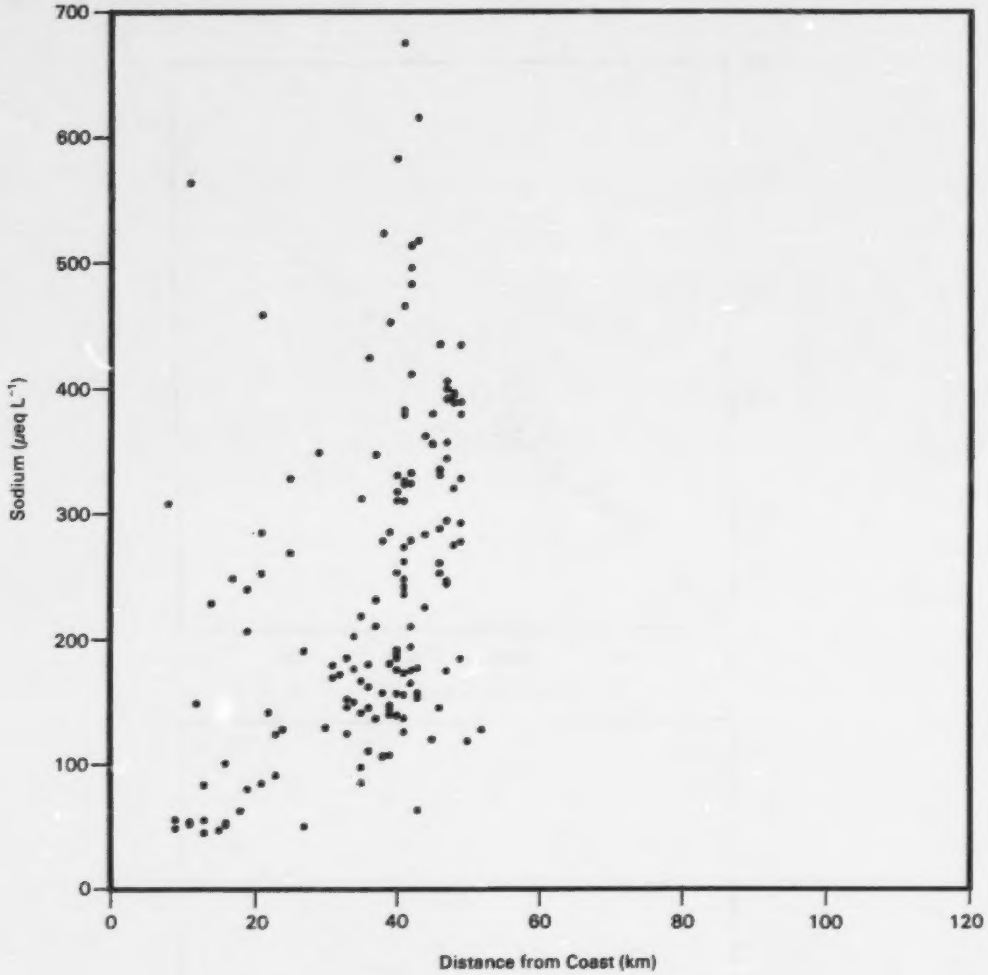
**Figure 5-16.** Lake water sodium concentration ($\mu$eq $L^{-1}$) versus lake distance (km) from coast for Region 1, Eastern Lake Survey-Phase I.



1966-67 (Field et al. 1973), have reported water pollution as a result of deicing salt application (Hanes et al. 1970). The effect of road salt and other anthropogenic factors can confound the relationship shown in Figure 5-16. This can be minimized by focusing on the lowest concentrations of sodium as a function of distance from the coast. In this case, the minimum concentrations of sodium show a sharp decline near 20 km and approach a concentration of about 30 $\mu$eq $L^{-1}$ at approximately 40 km from the coast. This agrees with Ogden (1982) who observed that about 80 percent of the marine aerosol in Nova Scotia is deposited within 20 km of the coast. Jackson (1905), Mairs (1967) and Haines and Akielaszek (1983) observed a similar pattern using chloride, but they observed that the influence of marine sources did not reach background concentrations until 75 to 100 km from the coast.

The relationship between sodium and distance from the coast for lakes in Subregion 3B (Florida) is presented in Figure 5-17. Only two of the sample lakes within 20 km of the coast in Florida (including the southern portion of Georgia) have sodium values exceeding 300 $\mu$eq $L^{-1}$ and in contrast to Region 1, the lakes in Florida exhibit a positive relationship between sodium and distance from the coast (slope = 5.0). This occurs despite the observation that the concentration of sodium in the precipitation appears to be low for the area containing

Figure 5-17. Lake water sodium concentration ($\mu$eq L$^{-1}$) versus lake distance (km) from coast for Subregion 3B, Eastern Lake Survey-Phase I.



most of the study lakes (Environmental Science and Engineering, Inc. 1983). This suggests that many of these lakes have a substantial contribution of sodium from the watersheds.

Further support for the idea that much of the sodium is not of atmospheric marine origin is shown by comparing sodium and chloride concentrations in Subregion 1D (Southern New England) with those in Subregion 3B (Florida, Figure 5-18). A line showing the expected fit of 0.86, based on the molar ratio of sodium to chloride in the ocean, is superimposed over the data. Lakes in Subregion 1D show good agreement with the expected ratio of sodium:chloride (slope = 0.827, $r^2 = 0.959$), whereas lakes in Subregion 3B show a slope of 0.642 and greater variability in the ratio ($r^2 = 0.796$). Lakes affected by road salt in Subregion 1D cannot be distinguished from sea spray sources on the basis of this relationship.

Table 5-7 shows the regression statistics for sodium versus chloride for all subregions. The degree of association between the variables is strongest in Region 1 where the regression generally explains over 94 percent of the variance, and the slope is generally close to the expected ratio of sea-salts. Lakes in Region 2 show greater scatter in the relationship, although this appears to be related to the low concentrations of sodium and chloride in this region (Section 4.8., Table 4-30). Subregion 3A shows a far greater ratio of sodium:chloride than

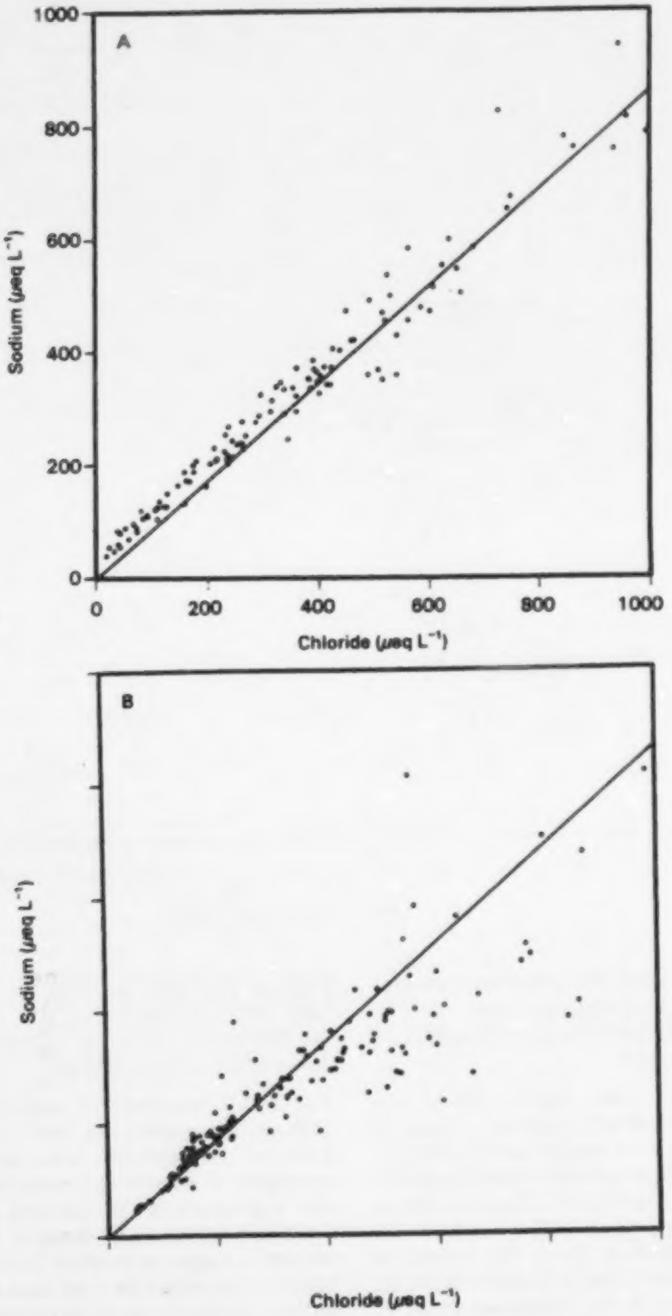


**Figure 5-18.** Relation of sodium ($\mu$eq $L^{-1}$) to chloride ($\mu$eq $L^{-1}$) for lakes in Subregions 1D (A) and 3B (B), Eastern Lake Survey-Phase I. (The line represents the expected ratio (a slope of 0.86) of sodium to chloride in the ocean.)

**Table 5-7.** **Regression Statistics for Sodium (Dependent) versus Chloride (Independent) by Region for Concentrations from 0 to 1000 μeq L$^{-1}$, Eastern Lake Survey-Phase I**

| Subregion | n | Intercept | Slope* | r$^2$ |
|---|---|---|---|---|
| 1A | 200 | 25 | 0.811 | 0.898 |
| 1B | 152 | 10 | 0.838 | 0.954 |
| 1C | 204 | 34 | 0.876 | 0.950 |
| 1D | 112 | 32 | 0.827 | 0.959 |
| 1E | 183 | 30 | 0.938 | 0.970 |
| 2A | 158 | 33 | 0.710 | 0.815 |
| 2B | 155 | 15 | 0.825 | 0.722 |
| 2C | 187 | 17 | 0.705 | 0.837 |
| 2D | 141 | 24 | 0.713 | 0.723 |
| 3A | 110 | 10 | 1.600 | 0.780 |
| 3B | 153 | 45 | 0.642 | 0.796 |

*Expected sea-salt ratio = 0.86 (Holland 1978)

observed in other subregions. The most plausible explanation for the high sodium:chloride ratio in 3A is weathering of the shale common to this area.

Deviations from the expected sea-salt ratio of 0.86 in precipitation and lakes have been attributed to anthropogenic sources (e.g., road salt, sewage, agriculture), exchange of marine sodium for divalent cations (Thompson 1982), exchange of sodium with H$^+$ (Rosenqvist 1978), contributions of excess sodium or chloride from the soil (Junge and Werby 1958, Lebowitz and de Pena 1985), and loss of chloride particles by volatilization of chloride as HCl (Eriksson 1960).

In view of the positive relationship between sodium and distance from the coast in Subregion 3B, the most likely dominant source of the high sodium (and other major ions) in many Florida lakes is contribution from shallow groundwater aquifers. Heath and Conover (1981) report that the median conductivity of public water supplies derived from shallow sand aquifers in Florida is 520 μS cm$^{-1}$ (range 220 to 988). However, a more complete evaluation of the chemistry of lakes, groundwater, and deposition is required before this issue can be resolved.

Although the concentration of calcium exceeds magnesium in all subregions, except Subregion 3B, the relationship of calcium to magnesium is highly variable among and within subregions. Figure 5-19 shows plots of calcium versus magnesium for Northcentral Wisconsin (2C) and Florida (3B) and illustrates extreme cases of this relationship among the subregions. Lakes in Subregion 2C are located in a similar geologic setting almost entirely within the Wisconsin Valley glacial lobe. This relative homogeneity of surficial geological material probably contributes to the high degree of correlation ($r^2$ = 0.891). In contrast, the lakes in Florida (3B) are located over a variety of different soil types and surficial and bedrock geology, and have groundwater contributions (Heath and Conover 1981). The regression results for calcium and magnesium are shown for all subregions in Table 5-8. Only Subregion 3B exhibits a slope of <1, whereas Subregion 1A and 1E have slopes >2. The degree of association between calcium and magnesium is quite high in Subregions 2B, 2C and 2D. The greater degree of scatter observed in Subregion 2A is most likely attributable to the variety of bedrock source material.

**Table 5-8.** **Regression Statistics for Calcium (Dependent) versus Magnesium (Independent) by Region for Concentrations from 0 to 1000 μeq L$^{-1}$, Eastern Lake Survey-Phase I**

| Subregion | n | Intercept | Slope | r$^2$ |
|---|---|---|---|---|
| 1A | 196 | 33 | 2.364 | 0.756 |
| 1B | 150 | 72 | 1.706 | 0.554 |
| 1C | 201 | 59 | 1.946 | 0.539 |
| 1D | 124 | 14 | 1.479 | 0.594 |
| 1E | 181 | 23 | 2.373 | 0.451 |
| 2A | 158 | 17 | 1.514 | 0.471 |
| 2B | 145 | 16 | 1.907 | 0.836 |
| 2C | 187 | −4 | 1.756 | 0.891 |
| 2D | 124 | −14 | 1.685 | 0.948 |
| 3A | 110 | 5 | 1.650 | 0.641 |
| 3B | 137 | 85 | 0.579 | 0.442 |

### 5.2.5.3 Relationships Among Major Ions

The previous descriptions of lake chemistry among subregions have been presented largely on the basis of absolute concentrations. Another useful approach to evaluate populations of lakes, particularly for anions and cations, is to compare ratios of ions. Figures 5-20, 5-21 and 5-22 present ratios of major anions to major cations as trilinear plots (ternary diagrams) (Hem 1970). Like the cation/anion bar charts (Figures 5-14 and 5-15), these plots include only the major ions and exclude ions that may be important in a small number of these lakes. These ions with typically low concentrations are discussed further in Section 5.2.6. The axes on the plots represent the percentage concentration of the ion or pair of ions, where values range from 0 to 100 percent, increasing in the direction of the arrows. A point representing the percentage ion composition for a lake is plotted once on each triangle for the cations and anions and is plotted a third time on the parallelogram for the pairs of cations and anions. Thus a lake with 100 percent $Ca(HCO_3)_2$ would appear in the extreme lower left portion of each triangle and would appear in the left corner of the parallelogram. A lake acidified by sulfuric acid would be expected to appear near the apex of the parallelo-

Figure 5-19. Relationship of calcium (μeq $L^{-1}$) to magnesium (μeq $L^{-1}$) for lakes in Subregions 2C (A) and 3B (B), Eastern Lake Survey-Phase I.

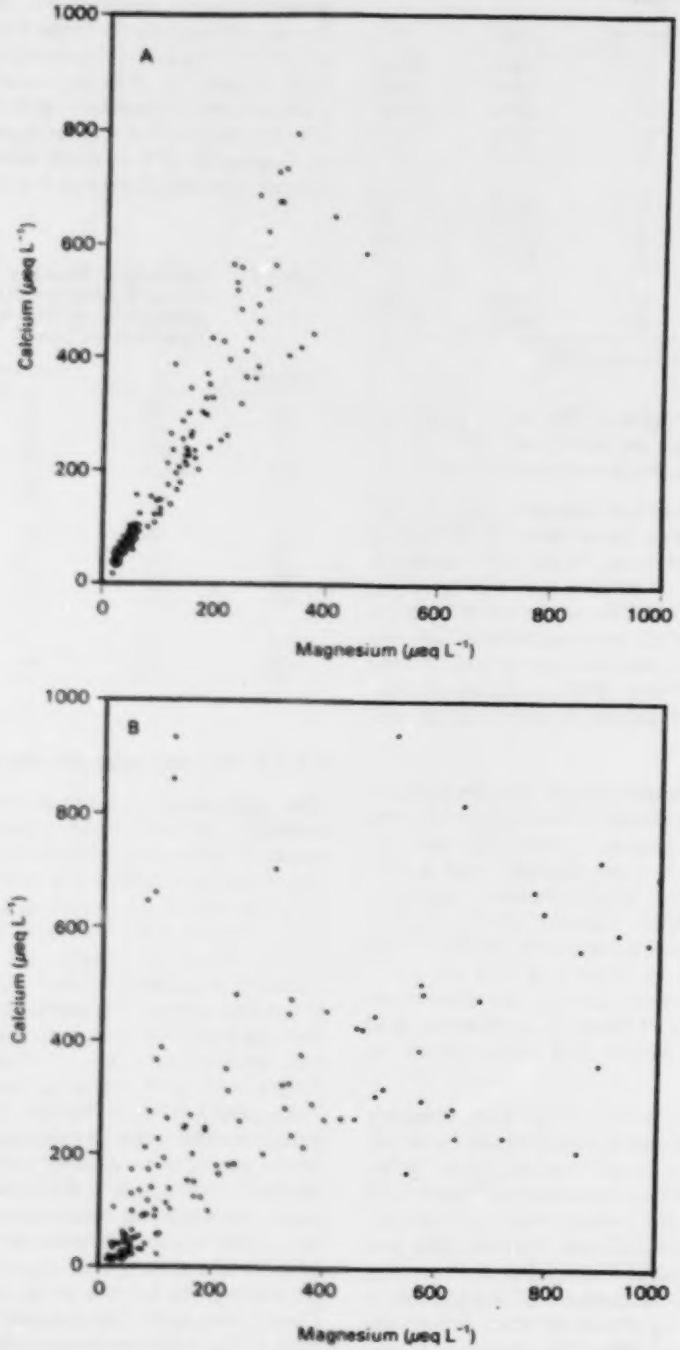
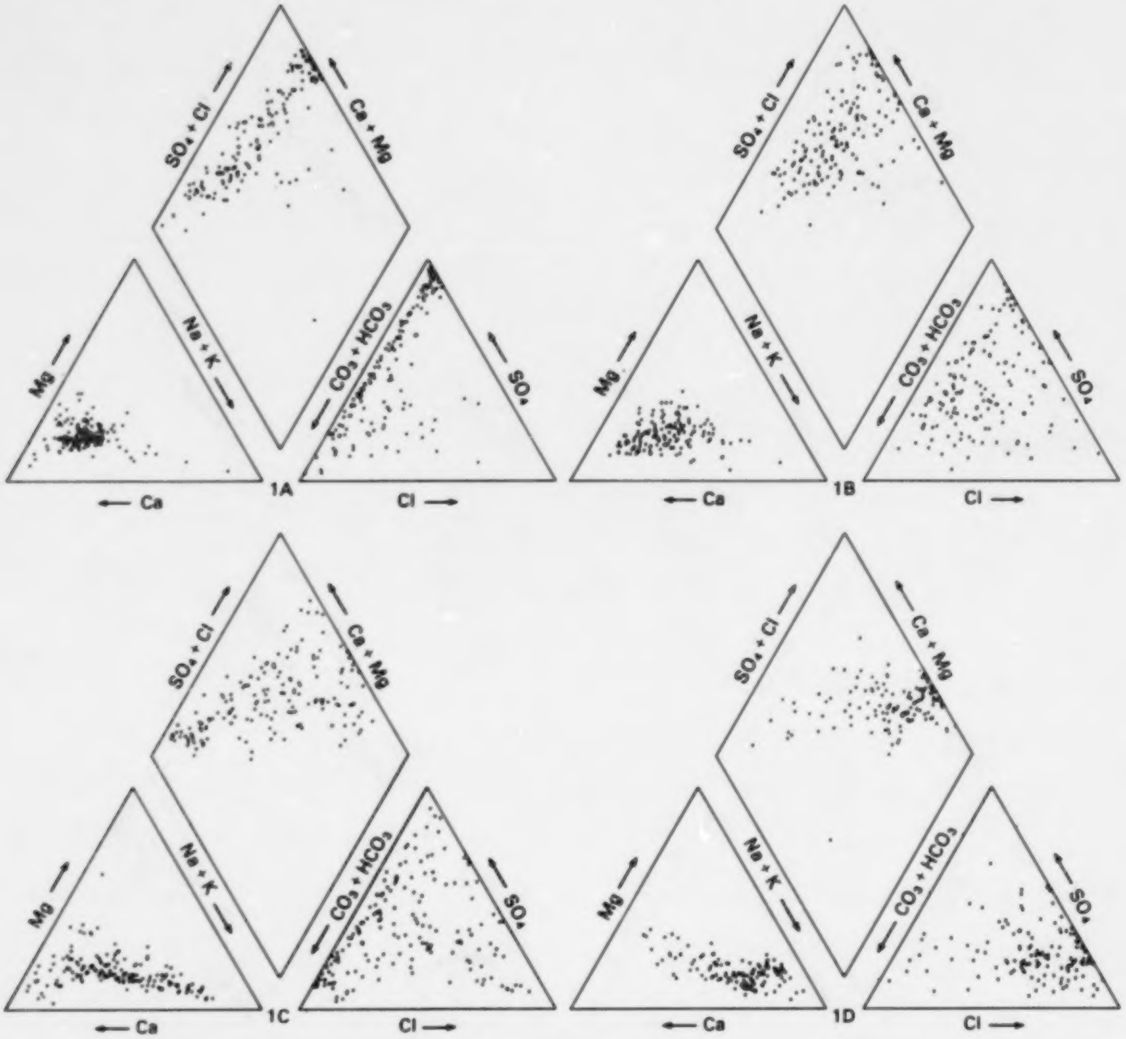


Figure 5-20. Trilinear plots of major anions and cations in Subregions 1A, 1B, 1C and 1D, Eastern Lake Survey -Phase I.

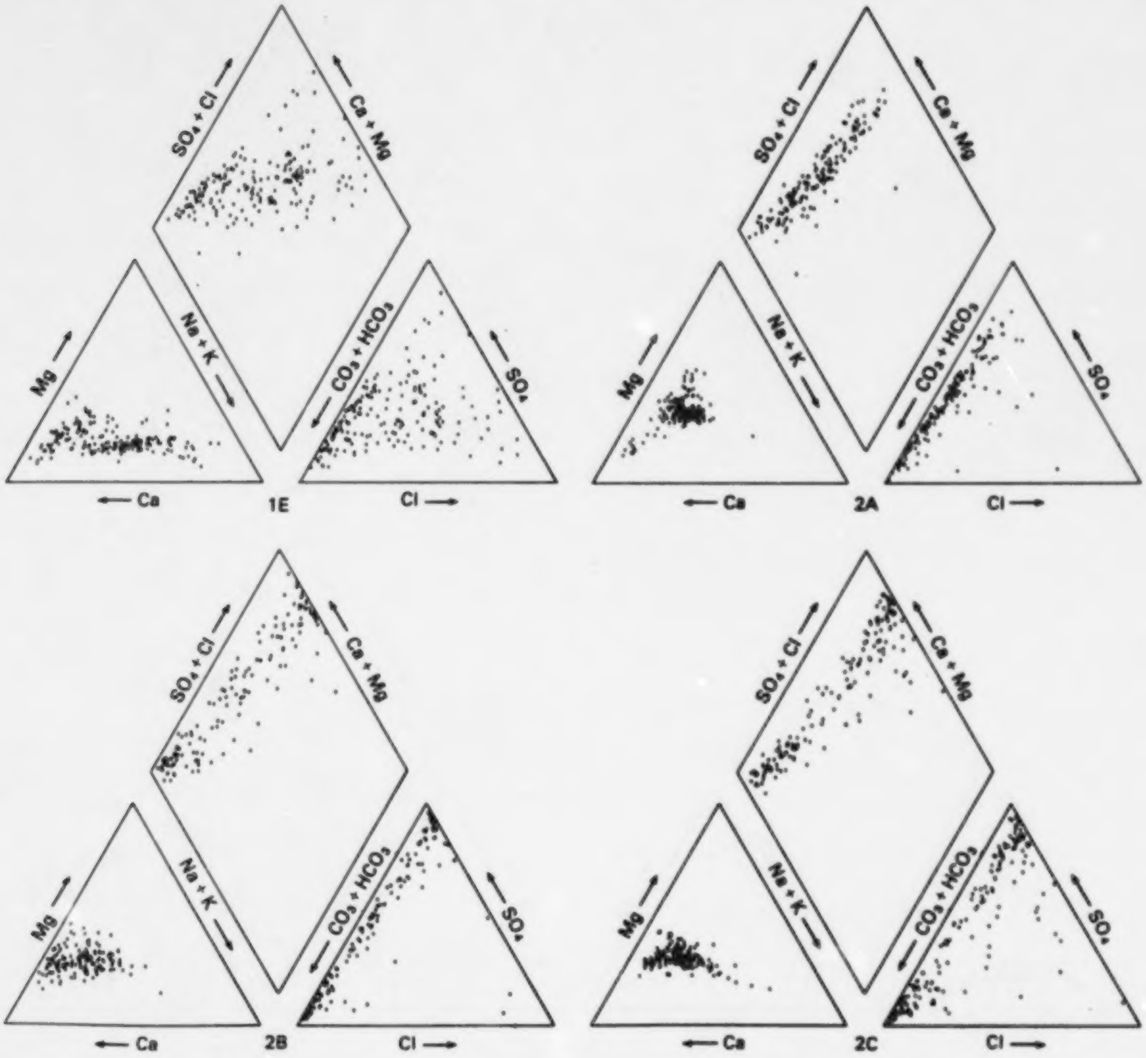


gram. Although these trilinear plots suffer from two deficiencies (i.e., they neither show differences in concentrations, nor do they include other ions of possible importance), they are useful for displaying patterns among the major ions.

There is considerable scatter present in the relationships of ions among and within regions. The ratios of anion concentrations generally exhibit a far greater degree of variability than observed for the ratios of cation concentrations. This is consistent with the observation discussed in Section 5.2.5.2 (Table 5-5) showing that the order of dominant anions changed with increasing concentrations. The ratios of cation concentrations show relatively little variability in Subregions 1A, 1B, all of Region 2, and Subregion 3A. The contribution of road salt, sea-salt, and groundwater sources of sodium is evident in Subregions 1C, 1D, 1E and 3B.

The plots for anions exhibit several distinct patterns. Subregions 1A, 2A, 2B, 2C and 2D could be classified as relatively high sulfate, low chloride waters. The bicarbonate concentrations are in some cases very low in Subregions 1A, 2B and 2C and the lakes in these three subregions show a high degree of similarity of anion ratios. Subregions 1D and 3B are high chloride areas with a moderate degree of variability in anion concentration ratios. Subregion 3A is the only subregion in which the

Figure 5-21. Trilinear plots of major anions and cations in Subregions 1E, 2A, 2B and 2C, Eastern Lake Survey -Phase I.



lakes are consistently bicarbonate systems with low concentrations of organic acids. Subregions 1B, 1C, and 1E are distinct from the other subregions because of the lack of any distinct pattern in anion composition.

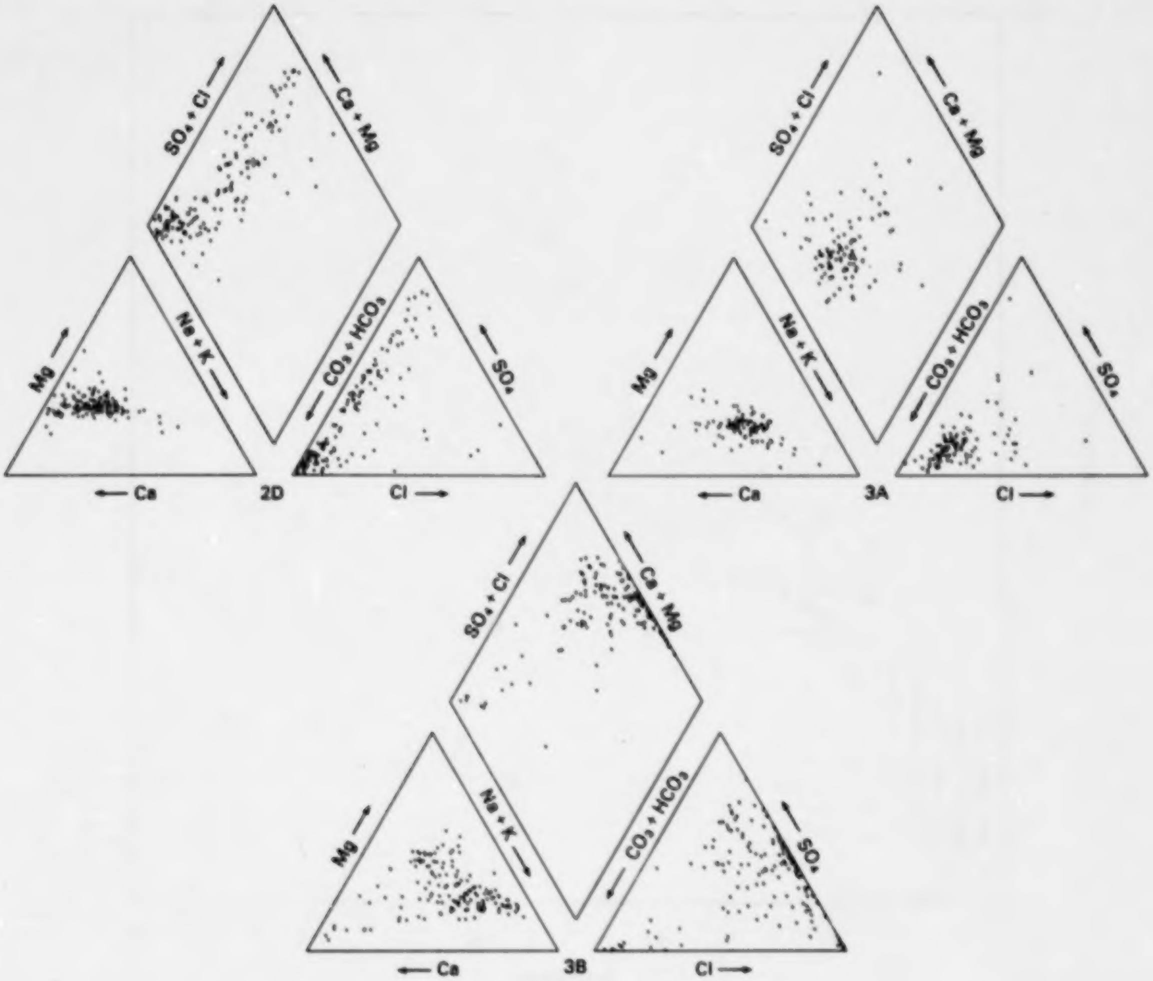
### *5.2.6 Dissolved Organic Carbon*

#### 5.2.6.1 *Color and DOC*

Water passing through plant materials leaches complex organic compounds that are resistant to decomposition. These organic compounds often contain quinoid functional groups that impart a brown color to water (Gjessing 1976). Because of this property, color often has been used as a surrogate for DOC.

Regression equations were computed to evaluate the relationship between DOC and true color for lakes in each subregion (Table 5-9). The intercepts ranged from 1.66 to 2.59 mg $L^{-1}$ DOC for subregions in the Northeast, whereas the intercepts for the Upper Midwest ranged from 2.20 to 5.69 mg $L^{-1}$ DOC. Only the Southern Blue Ridge (3A) had an intercept not significantly different from zero. Three subregions with large proportions of low ANC lakes 1A, 2C and 3B, had similar intercepts of approximately 2 mg $L^{-1}$ DOC. Intercepts greater than zero indicate that some

Figure 5-22. Trilinear plots of major anions and cations in Subregions 2D, 3A and 3B, Eastern Lake Survey -Phase I.

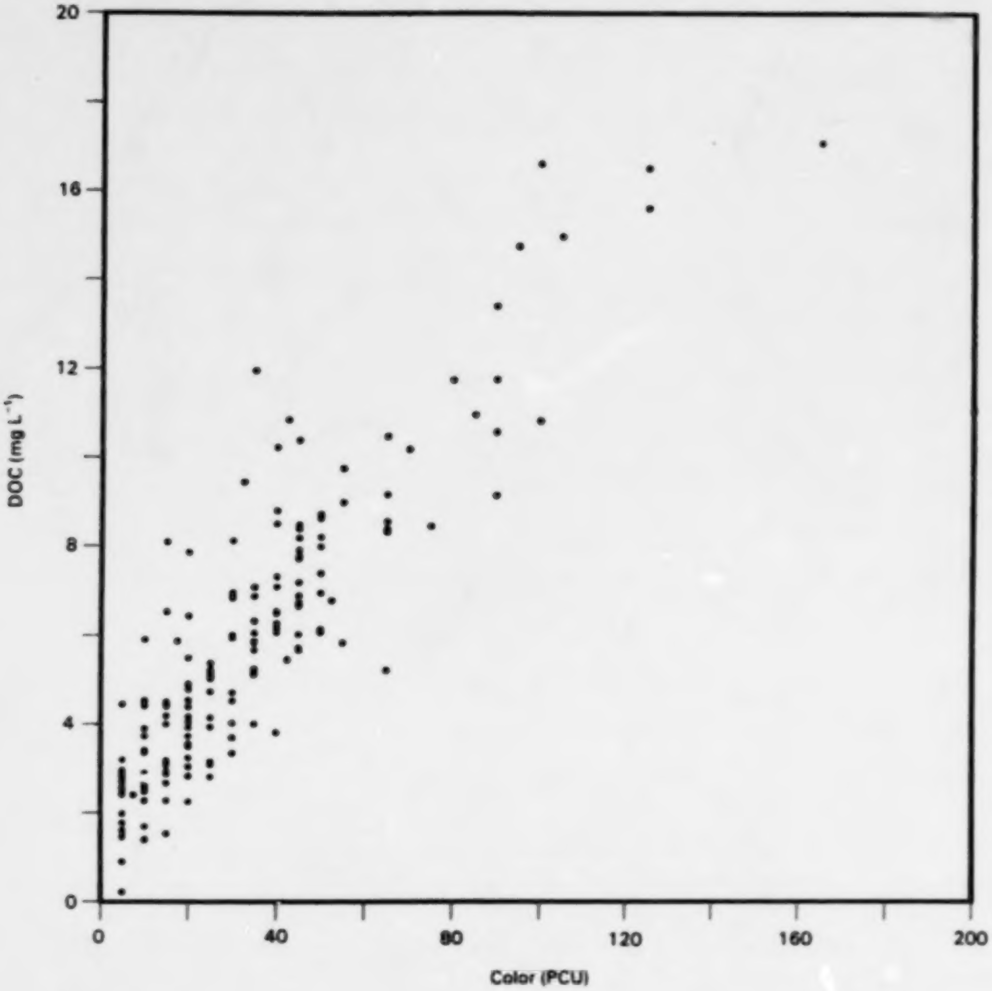


of the organic matter does not impart color to the water. This is consistent with the observations of Lamar and Goerlitz (1966) who isolated colorless carboxylic acids from stream water samples.

The slopes of the regressions between DOC and color ranged from 0.049 in the Southern Blue Ridge (3A) to 0.124 in Florida (3B), although most subregions showed slopes from 0.07 to 0.10. The low $r^2$ value for Subregion 1C is, in part, attributed to a possible analytical error for one DOC measurement; excluding this value from the analysis yields an intercept of 2.49, a slope of 0.083, and an $r^2$ of 0.564. A typical relationship between DOC and color is shown in Figure 5-23 for lakes in Maine (1E). Considerable scatter is evident such that for a given color value, the DOC concentration may vary by several milligrams per liter. Such variations in observed DOC concentrations are expected because of the effect increasing pH has on increasing the color of surface waters (Black and Christman 1963).

The lakes in Northeastern Minnesota (2A) exhibit an even greater degree of scatter between DOC and color, particularly at high color (Figure 5-24). The lowest DOC value in Subregion 2A is a suspected analytical error; removal of this observation from the regression results in an intercept of 5.21, a slope of 0.075, and an $r^2$ of 0.587. However, this does not explain the relatively poor agreement between DOC and color in Northeastern Minnesota (2A).

**Figure 5-23.** Dissolved organic carbon (0-20 mg L$^{-1}$) versus color (0-200 PCU) for Subregion 1E, Eastern Lake Survey - Phase I.



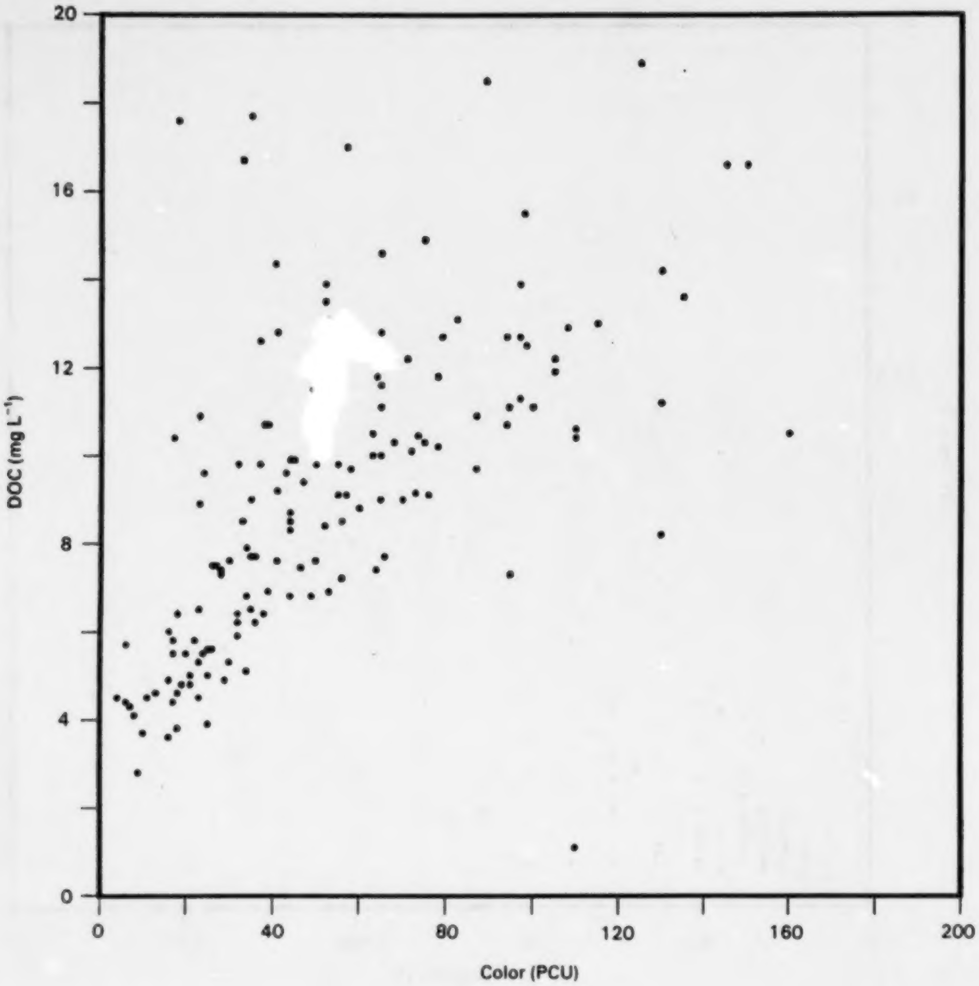
There is a variety of factors that could contribute to poor agreement between DOC and color (e.g., effect of pH, different sources of DOC, different residence times in the lakes), but no single factor provides a satisfactory explanation in this relatively homogeneous area (Section 6.2).

The extremely small slope for lakes in Subregion 3A (Figure 5-25) can be attributed to the low concentrations of organic acids in these waters (as indicated by the lack of any appreciable anion deficit). The most probable source of color in these lakes is from light scattering caused by inorganic colloids.

The slope for Florida lakes (3B) is significantly greater than for other subregions, indicating that for a given DOC the expected color is low compared to other subregions. Florida lakes are exposed to more intensive sunlight and have a higher mean annual temperature than lakes in Regions 1 and 2. Both ultraviolet radiation (Il'in and Orlov 1973) and higher temperatures (Gjessing 1976) contribute to a reduction in color. Gjessing also points out that color reduction of humic acids can occur with increasing salt concentrations. However, the small slope in Southern New England (1D), a subregion with equally high sodium chloride concentrations, suggests that the effect of salt on color reduction on a regional basis may be small. Finally, vegetation differences between Florida and other subregions could contribute to a different molecular composition of humic and fulvic acids.

Although there is a general relationship between DOC and color, the relationship is highly variable

Figure 5-24. Dissolved organic carbon (0-20 mg $L^{-1}$) versus color (0-200 PCU) for Subregion 2A, Eastern Lake Survey -Phase I.

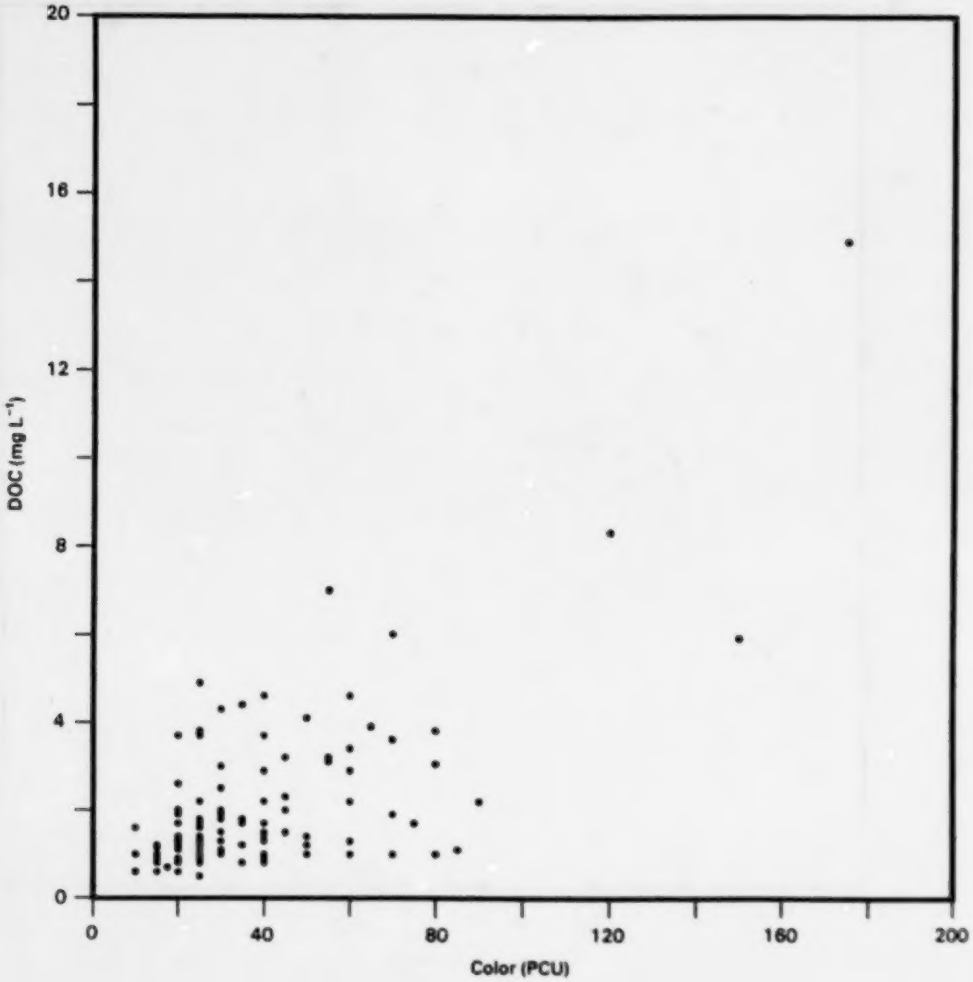


among subregions. A number of reasons may explain the difference of the relationship in Florida compared to those in the Northeast and the Upper Midwest, but no simple explanation is evident to explain the variability within Regions 1 and 2.

### 5.2.6.2 Anion Deficit

The principle of electroneutrality states that the equivalent sum of cations must equal the equivalent sum of anions if all contributing ions are measured. In addition to serving as an analytical tool for quality assurance checks, evaluation of ion balances provides additional insight into regional lake chemistry. Many of the lakes sampled had anion deficits; i.e., the sum of measured anions was less than the sum of measured cations. Assuming no analytical error, the deficit reflects an inability to measure organic anions directly. It can be inferred that the anion deficit is caused by unmeasured organic anions if a relationship between anion deficit and DOC can be established. Table 5-10 shows the population estimates, the quintiles $Q_1$ and $Q_4$, and median for anion deficit by subregion. Subregion 3B contains the highest estimates of anion deficit at the median and $Q_4$, whereas Subregion 2A contains the highest estimate at the 20th percentile ($Q_1$). Lakes in the Upper Midwest (with the possible exception of Subregion 2C), contain substantially higher estimates of anion deficit than lakes in the Northeast. Subregions 1A, 1B, 1D and 3A have no anion deficit in over 20 percent of the lakes. Caution should be used in interpreting the population estimates of anion deficit because subregions with high ionic concentrations (such as Florida) can ex-

Figure 5-25. Dissolved organic carbon (0-20 mg L$^{-1}$) versus color (0-200 PCU) for Subregion 3A, Eastern Lake Survey - Phase I.



hibit a deceptively high anion deficit related to greater absolute analytical error at high ionic concentrations.

There is a strong linear relationship between the sums of anions and cations among all regions and within most subregions. Summary statistics for regressions between the sum of major anions and cations are shown in Table 5-11 for darkwater (color > 30 PCU) and clearwater lakes (color ≤30 PCU). Complete agreement between measured anions and cations would result in an intercept of zero and a slope of one. Most lakes show an intercept and slope less than one, indicating a systematic underestimation of the anions. This pattern is even more apparent in the darkwater lakes. The subregions in the Upper Midwest generally exhibit the greatest departure from the 1:1 relationship. Furthermore, the slopes for lakes in the Upper Midwest and Florida show a substantial decrease in slope between the clearwater and darkwater lakes that indicates an increasing concentration of unmeasured anions at higher ionic concentrations. This is in contrast to the pattern for lakes in the Northeast that shows an additive effect to the anion deficit in the darkwater lakes (i.e., the slopes between clearwater and darkwater lakes are similar, with only the intercepts showing a substantial difference).

Intercepts greater than one indicate a cation deficit caused by not measuring all cations (assuming no analytical error). In the Northeast, only Subregion 1A shows a positive intercept for both clearwater

**Table 5-9.** Regression Statistics for DOC (0-20 mg $L^{-1}$, Dependent) versus Color (0-200 PCU, Independent) by Subregion, Eastern Lake Survey-Phase I

| Subregion | n | Intercept | Slope | $r^2$ |
|---|---|---|---|---|
| 1A | 203 | 1.90 | 0.081 | 0.770 |
| 1B | 154 | 1.66 | 0.093 | 0.615 |
| 1C[+] | 213 | 2.59 | 0.072 | 0.451 |
| 1D | 127 | 1.77 | 0.077 | 0.753 |
| 1E | 181 | 2.46 | 0.096 | 0.732 |
| 2A[*] | 151 | 5.69 | 0.064 | 0.372 |
| 2B | 152 | 3.08 | 0.089 | 0.541 |
| 2C | 185 | 2.20 | 0.094 | 0.785 |
| 2D | 141 | 3.75 | 0.085 | 0.663 |
| 3A | 112 | 0.25 | 0.049 | 0.469 |
| 3B | 141 | 1.99 | 0.124 | 0.772 |

[+] Removal of one observation results in the following: intercept 2.49, slope 0.083, and $r^2$ 0.564.

[*] Removal of one observation results in the following: intercept 5.21, slope 0.075, and $r^2$ 0.587.

**Table 5-10.** Population Estimates of $Q_1$ (20th Percentile), Median and $Q_4$ (80th Percentile) Anion Deficit[*] ($\mu$eq $L^{-1}$) by Subregion, Eastern Lake Survey-Phase I

| Subregion | $Q_1$ | M | $Q_4$ |
|---|---|---|---|
| 1A | 0 | 24 | 49 |
| 1B | 0 | 13 | 45 |
| 1C | 3 | 26 | 60 |
| 1D | 0 | 0 | 35 |
| 1E | 13 | 42 | 85 |
| 2A | 48 | 78 | 118 |
| 2B | 20 | 55 | 150 |
| 2C | 12 | 34 | 73 |
| 2D | 29 | 81 | 148 |
| 3A | 0 | 0 | 16 |
| 3B | 12 | 98 | 187 |

[*] Anion deficit is expressed as the positive difference of $\Sigma$ cations $-$ $\Sigma$ anions; where $\Sigma$ anions $\geq$ $\Sigma$ cations, anion deficit = 0; and where the cations are $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $K^{+}$, $NH_4^{+}$, $H^{+}$, and the anions are $HCO_3^{-}$, $CO_3^{-2}$, $OH^{-}$, $SO_4^{-2}$, $Cl^{-}$, $F^{-}$, $NO_3^{-}$.

and darkwater lakes. A plot of the sum of anions versus sum of cations for lakes in the Adirondacks (1A; Figure 5-26) shows a group of dilute lakes with a cation deficit. Including $Al^{+3}$, $Fe^{+3}$ and $Mn^{+2}$ in the sum of cations resolves this anomaly and results in the following regression statistics for lakes in Subregion 1A: intercept −8.3, slope 0.890, and $r^2$ 0.966. Most subregions show an intercept near zero and a slope slightly less than one for clearwater lakes. The regressions for the darkwater lakes show a substantially lower intercept for all subregions except for Subregion 3A (Southern Blue Ridge). The close agreement between measured sums of anions and cations in Subregion 3A for both clearwater and darkwater lakes is expected considering the low DOC concentrations in these lakes (Figure 5-27). The lakes in Northeastern Minnesota (2A) are in strong contrast to those in the Southern Blue Ridge (3A) with respect to the relationship between anions and cations (Figure 5-28). It is evident that lakes through the range of ion concentrations exhibit a substantial anion deficit in Subregion 2A. Subregion 1D (Southern New England) is the only area with a slope greater than one for both clearwater and darkwater lakes. This subregion contained the lowest estimated concentrations of unmeasured anions among lakes in Region 1.

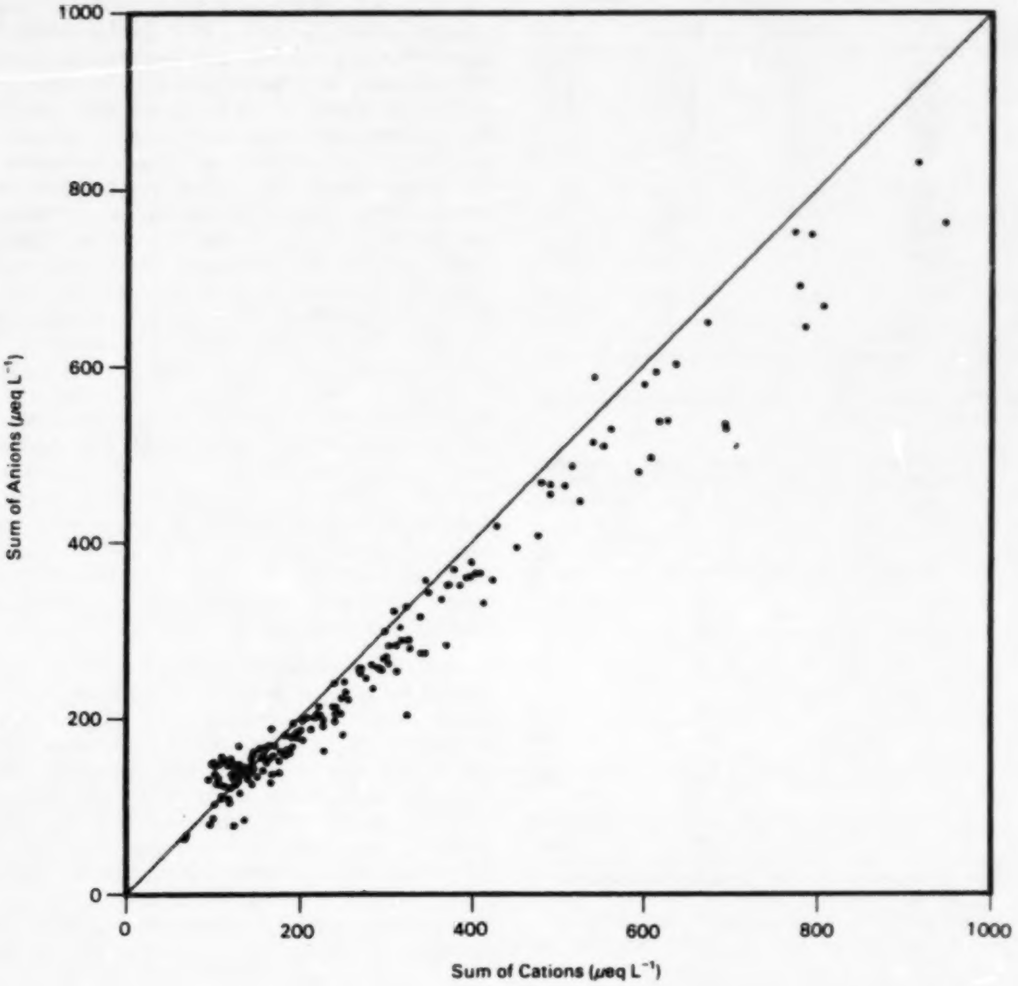
In order to evaluate further the nature of the unmeasured anions among subregions, the anion deficit was regressed against DOC. Table 5-12 shows the regression results computed including the anions and cations used in previous presentations and also computed with the addition of $Al^{+3}$ and $Fe^{+3}$ to the sum of cations. There is some uncertainty regarding the appropriate charge per ion for metals in lakewaters (Driscoll et al. 1983). The charge values of +3 were selected for this analysis to provide a basis for comparison to the results of Oliver et al. (1983). The addition of total aluminum

**Table 5-11.** Regression Statistics for the Sum of Anions (Dependent) versus the Sum of Cations[*] (Independent) by Subregion, Eastern Lake Survey-Phase I

| | Clearwater Lakes | | | | Darkwater Lakes | | | |
|---|---|---|---|---|---|---|---|---|
| Subregion | n | Intercept | Slope | $r^2$ | n | Intercept | Slope | $r^2$ |
| 1A | 127 | 23.9 | 0.866 | 0.981 | 60 | 7.4 | 0.843 | 0.967 |
| 1B | 103 | 4.2 | 0.987 | 0.974 | 38 | −28.8 | 0.987 | 0.975 |
| 1C | 125 | −5.8 | 0.960 | 0.980 | 60 | −27.6 | 0.941 | 0.971 |
| 1D | 66 | −5.8 | 1.042 | 0.978 | 28 | −42.0 | 1.043 | 0.978 |
| 1E | 101 | 6.5 | 0.901 | 0.971 | 76 | −54.1 | 0.946 | 0.933 |
| 2A | 42 | −32.6 | 0.958 | 0.988 | 109 | −55.2 | 0.873 | 0.944 |
| 2B | 71 | −0.3 | 0.933 | 0.960 | 59 | −31.5 | 0.837 | 0.897 |
| 2C | 117 | −7.3 | 0.944 | 0.992 | 60 | −35.2 | 0.876 | 0.963 |
| 2D | 45 | −10.6 | 0.907 | 0.991 | 65 | −41.1 | 0.900 | 0.945 |
| 3A | 59 | 4.0 | 0.980 | 0.963 | 46 | 0.5 | 1.018 | 0.981 |
| 3B | 49 | 6.5 | 0.914 | 0.981 | 42 | −59.6 | 0.865 | 0.917 |

[*] Anions included are $HCO_3^{-}$, $OH^{-}$, $CO_3^{-2}$, $SO_4^{-2}$, $Cl^{-}$, $NO_3^{-}$, $F^{-}$;
Cations included are $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $K^{+}$, $H^{+}$, $NH_4^{+}$.

Figure 5-26. Relationship of the sum of anions ($\mu$eq L$^{-1}$) to the sum of cations ($\mu$eq L$^{-1}$) for lakes in Subregion 1A, Eastern Lake Survey-Phase I.



and iron to the sum of cations improves the agreement between anion deficit and DOC in all subregions except Florida (3B). Despite this improvement, the DOC explains less than 50 percent of the variance for anion deficit in seven of the eleven subregions. Better agreement between anion deficit and DOC generally occurs in subregions with moderate to high concentrations of DOC.

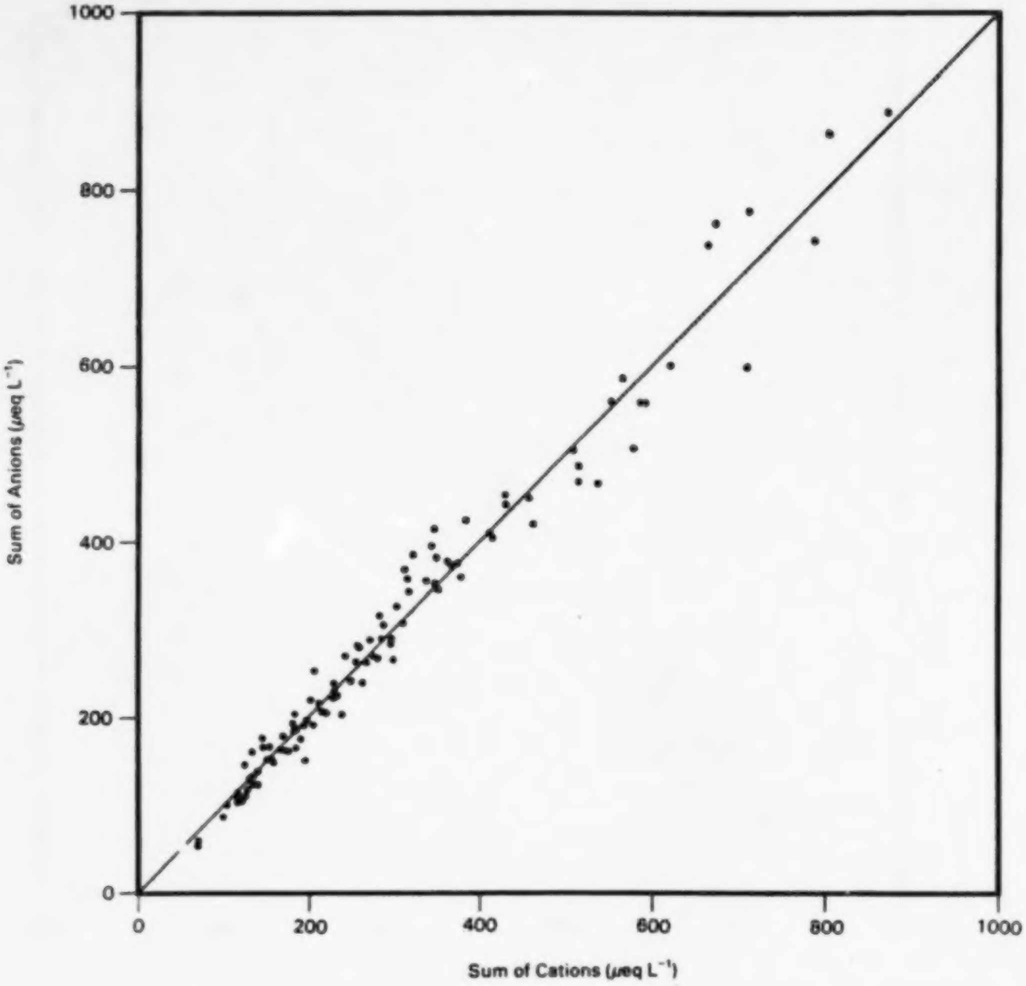
The slope of the relationship between anion deficit and DOC has been used by others to estimate the carboxylic acid content of the organic material (Eshleman and Hemond 1985; Oliver et al. 1983). The reported conversions for DOC to carboxylic acid in surface waters range from 4.78 $\mu$eq/mg C in bog waters (Gorham et al. 1985) to 22 $\mu$eq/mg C in the Satilla River, Georgia (Beck et al. 1974). Oliver et al. (1983) reported an average of 10.5 $\mu$eq/mg C based on a variety of waters in North America. The conversion estimated here (using $Al^{+3}$ and $Fe^{+3}$) ranges from 6.3 $\mu$eq/mg C in Subregion 3A to 11.8 $\mu$eq/mg C in Subregion 1A. Use of 10 $\mu$eq/mg C as proposed by Oliver et al. (1983) for all lakes may substantially overestimate (or possibly underestimate for some areas) the organic anion concentrations depending on the subregion.

## 5.3 Hydrology

### *5.3.1 Hydrologic Lake Type*

The physical features of a watershed and lake control how water is collected and routed to a lake, and

**Figure 5-27.** Relationship of the sum of anions ($\mu$eq L$^{-1}$) to the sum of cations ($\mu$eq L$^{-1}$) for lakes in Subregion 3A, Eastern Lake Survey-Phase I.

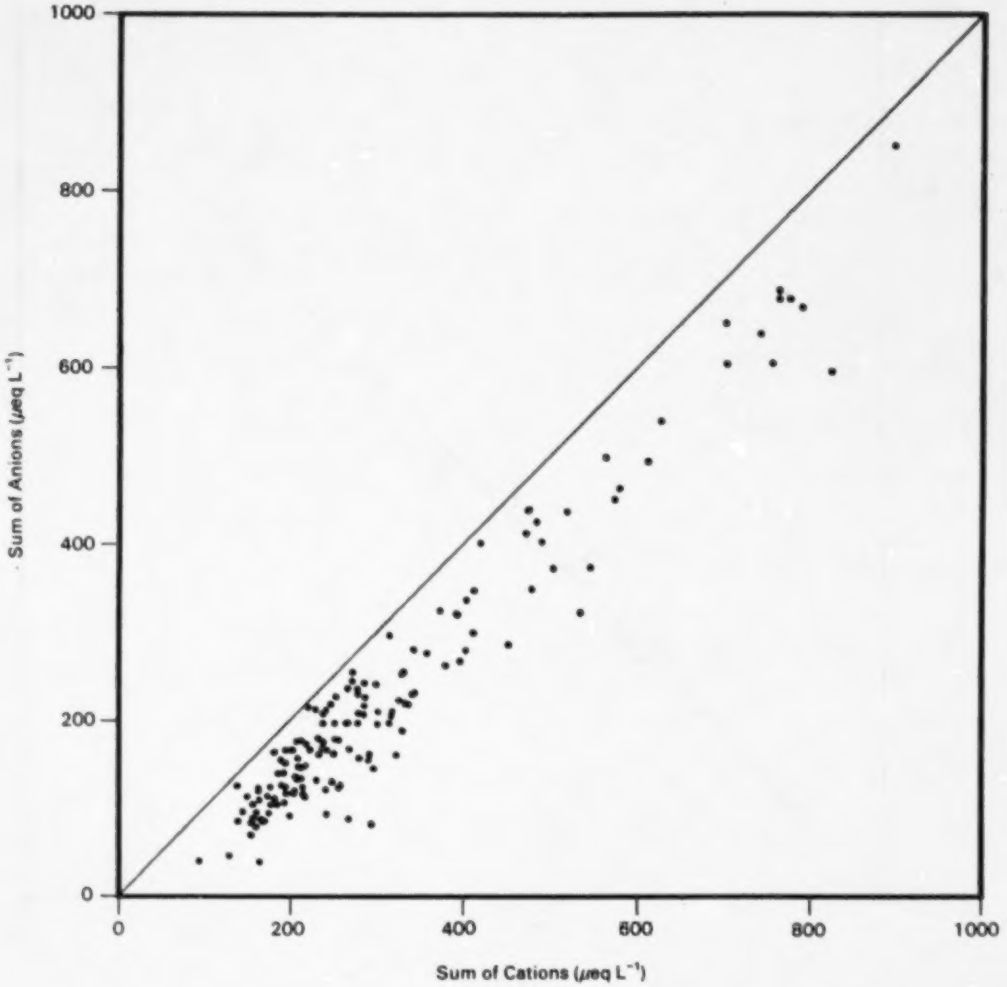


how rapidly water is replaced in a lake. Therefore, watershed hydrology can play a major role in determining the chemical composition of a lake. Lake chemistry represents the integration of the chemistry of deposition and the influence of factors such as watershed vegetation, soils, geology and in-lake processes.

The influence of hydrology on the chemistry of lakes in the ELS-I was evaluated through two approaches. First, lake types were classified based on the presence of permanent surface water inlets and outlets identified on 1:24,000-, 1:25,000-, and 1:62,500-scale USGS topographic maps. The lakes were classified as follows: seepage (no inlets, no outlet); drainage (outlet); closed (inlets, no outlet); and reservoir (outlet control structure present). The objective of this initial classification was to distinguish those lakes that receive substantial chemical input from the watersheds (e.g., drainage, closed and reservoir lakes) from those that receive minimal contributions from the watersheds (e.g., seepage lakes).

The hydrologic interactions between lake and watershed are subject to considerable temporal and spatial variability (Winter 1977). The nature of the interaction is affected by many watershed characteristics that are likely best represented by a continuum rather than discrete classifications. Although the hydrologic classifications inadequately represent the complex nature of hydrologic contri-

Figure 5-28. Relationship of the sum of anions ($\mu$eq L$^{-1}$) to the sum of cations ($\mu$eq L$^{-1}$) for lakes in Subregion 2A, Eastern Lake Survey-Phase I.



butions to many lakes, they provide a useful framework for exploring relationships among variables.

Population estimates for the number of lakes presented in Table 5-13 revealed marked contrasts in the abundance of lakes by hydrologic types among subregions. Region 1 showed a high percentage of drainage lakes and Subregions 2C, 2D, and 3B showed a high percentage of seepage lakes. In the Upper Midwest, Subregions 2A and 2B contained a majority of drainage lakes (74 and 51%, respectively). In the Southern Blue Ridge (3A), an estimated 90 percent of the lakes were reservoirs, a feature in strong contrast to other subregions. Only Subregions 1B (Poconos/Catskills) and 1D (Southern New England) contained significant percentages of reservoirs (42 and 29%, respectively). The drainage lakes were the most common type in the Northeast, whereas seepage lakes were common in the Upper Midwest and Florida. Closed lakes (those containing an inlet, but no permanent surface water outlet) were relatively uncommon in all regions.

Population estimates of the median values of six primary chemical variables are also shown in Table 5-13. Estimates of median extractable aluminum are shown, but these should be interpreted with caution because the median values were near the system decision limit of 8 $\mu$g L$^{-1}$. When the sample size for a lake type within a region was less than 10, estimates of the lake chemistry are not provided. Seepage lakes exhibited lower median ANC values than drainage lakes in all subregions; typically seepage lakes also had lower $Ca^{+2}$ and $SO_4^{-2}$ con-

Table 5-12. **Regression Statistics for Anion Deficit (0-200 $\mu eq\ L^{-1}$, Dependent) versus DOC (0-200 mg $L^{-1}$, Independent) Computed without Metals ($Al^{+3}$, $Fe^{+3}$) and with Metals, Eastern Lake Survey-Phase I**

| | Anion Deficit[a] Excluding $Fe^{+3}$ and $Al^{+3}$ | | | | Anion Deficit[b] Including $Fe^{+3}$ and $Al^{+3}$ | | | |
|---|---|---|---|---|---|---|---|---|
| Subregion | n | Intercept | Slope | $r^2$ | n | Intercept | Slope | $r^2$ |
| 1A | 196 | −13.13 | 9.45 | 0.330 | 196 | −10.39 | 11.82 | 0.469 |
| 1B | 154 | −9.31 | 7.06 | 0.315 | 154 | −8.99 | 8.41 | 0.343 |
| 1C | 208 | 1.85 | 5.94 | 0.206 | 207 | 4.06 | 7.59 | 0.303 |
| 1D | 120 | −10.18 | 5.61 | 0.328 | 120 | −15.06 | 8.04 | 0.483 |
| 1E | 181 | −7.95 | 9.42 | 0.620 | 180 | −7.25 | 11.04 | 0.681 |
| 2A | 148 | 18.90 | 6.32 | 0.390 | 148 | 18.67 | 7.90 | 0.426 |
| 2B | 141 | −4.81 | 7.91 | 0.472 | 140 | −5.93 | 9.58 | 0.553 |
| 2C | 184 | −11.10 | 9.36 | 0.651 | 179 | −12.72 | 10.91 | 0.651 |
| 2D | 131 | −14.04 | 9.26 | 0.520 | 129 | −15.63 | 10.50 | 0.579 |
| 3A | 110 | 4.87 | 2.30 | 0.037 | 110 | 6.34 | 6.31 | 0.130 |
| 3B | 126 | 6.12 | 8.14 | 0.433 | 120 | 10.90 | 7.89 | 0.383 |

[a] Anion deficit computed using: $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $K^{+}$, $H^{+}$, $NH_4^{+}$; $HCO_3^{-}$, $OH^{-}$, $CO_3^{-2}$, $Cl^{-}$, $NO_3^{-}$, $F^{-}$

[b] Cations included are: $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $K^{+}$, $H^{+}$, $NH_4^{+}$, $Al^{+3}$, $Fe^{+3}$; (anions same as in a).

centrations. Median DOC values were also lower in seepage lakes compared to drainage lakes among all subregions except 1C and 2A.

The differences in median ANC between drainage and seepage lakes within subregions ranged from only 3 $\mu eq\ L^{-1}$ in Subregion 1A to 910 $\mu eq\ L^{-1}$ in Subregion 2D. These differences in ANC were generally much greater between drainage and seepage lakes in Region 2 and Subregion 3B and were relatively small for those lakes in Region 1. This suggests either a greater volume of groundwater inflow or that the chemical composition of groundwater in Region 2 and Subregion 3B contributes greater ANC to the drainage lakes compared to drainage lakes in Region 1. The results for median ANC in the Adirondack (1A) lakes are notable, not only because there is little difference between seepage and drainage lakes, but because the ANC of drainage lakes in Subregion 1A is also the lowest among drainage lakes across subregions.

Reservoirs in all subregions had among the highest median ANC and $Ca^{+2}$. This was expected in reservoirs because of the large size of the watersheds relative to the lake area. ANC values for closed lakes were most similar to those for reservoirs in Region 1, but were most similar to those for seepage lakes in Region 2 and Subregions 3A and 3B.

The relative importance of hydrologic lake types among the regions is contrasted in Figure 5-29. The estimated number of lakes in each region is indicated by the total height of the vertical bars. The number of lakes with ANC >200 $\mu eq\ L^{-1}$ is shown in white. The hydrologic lake types are represented for lakes with ANC $\leq$200 $\mu eq\ L^{-1}$. Of 7096 lakes (>4 ha and $\leq$2000 ha; Table 4-12) in Region 1, the majority (4258; Table 4-15) have ANC $\leq$200 $\mu eq\ L^{-1}$. Of the lakes in Region 1 with ANC $\leq$200 $\mu eq\ L^{-1}$, the vast majority are drainage lakes. The relative proportions of low ANC drainage lakes to seepage lakes observed in Region 1 are reversed in Region 2 and Subregion 3B. This apparent regional difference in the hydrology of low ANC lakes highlights the need to include hydrology in assessing the impacts of acidic deposition.

### *5.3.2 Hydraulic Residence Time*

Use of hydrologic lake types is a qualitative approach for evaluating the relationship between lake chemistry and hydrology. A more quantitative approach to evaluating the relationship between hydrology and lake chemistry is to compute hydraulic residence time.[6] This is defined as the time required to exchange the volume of water in a lake.

$$\begin{array}{c}\text{Hydraulic}\\ \text{Residence}\\ \text{Time}\end{array} = \frac{\text{Lake Volume}}{\text{Total Volume of Inflow per Year}}$$

The hydraulic residence time of a lake can be important in response to acidic deposition for several reasons. A lake with a short residence time would presumably be more likely to respond to episodic events such as snowmelt. Also, one would expect such lakes to achieve a steady-state with respect to a given pollutant loading relatively quickly. In contrast, lakes with long hydraulic residence times likely would be slower to respond to changes in loading assuming other watershed features were

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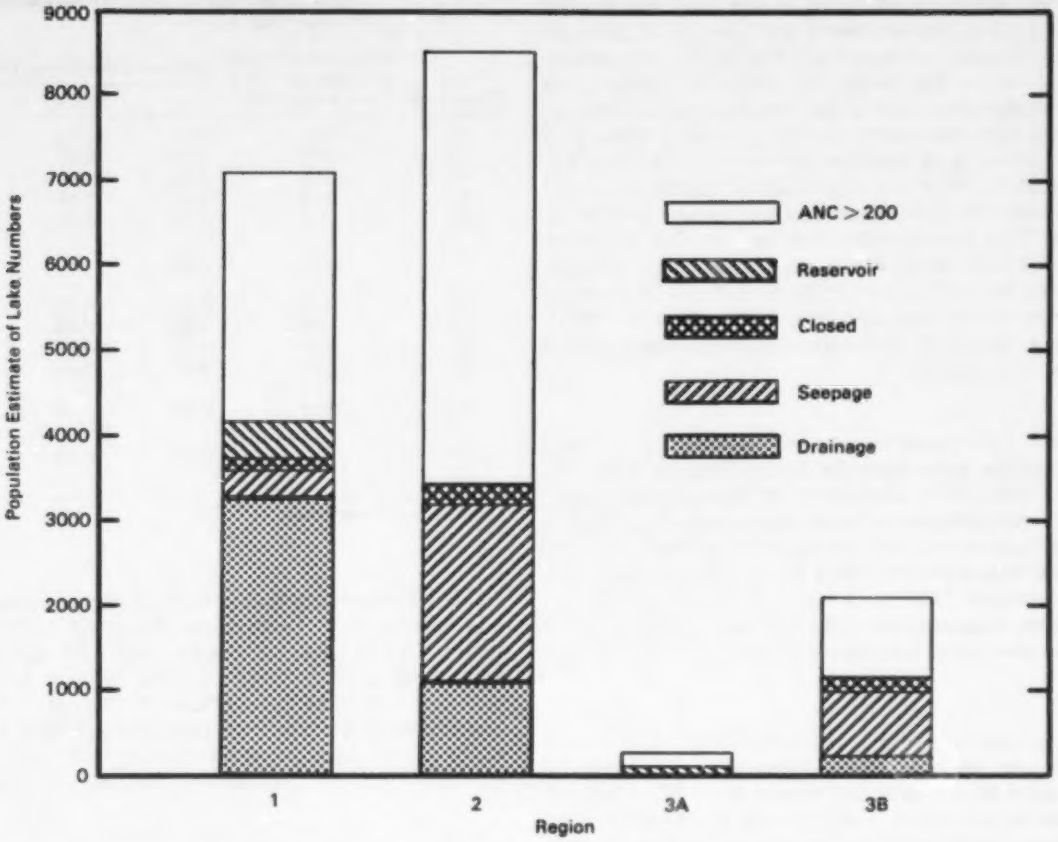
[6] This should not be confused with retention time, which is the average time a substance would remain in the lake.

**Table 5-13.** **Population Estimates of Lake Numbers by Hydrologic Types with Associated Median Values of Chemical Parameters, Eastern Lake Survey-Phase I**

| Subregion/ Region | Lake Type | Estimated Number of Lakes | pH | ANC ($\mu eq\ L^{-1}$) | DOC ($mg\ L^{-1}$) | $Ca^{+2}$ ($\mu eq\ L^{-1}$) | $SO_4^{-2}$ ($\mu eq\ L^{-1}$) | Al (ext) ($\mu g\ L^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 1A | Drainage | 991 | 6.58 | 88 | 4.3 | 139 | 119 | 10 |
| | Seepage | 110 | 6.50 | 85 | 3.4 | 123 | 106 | 7 |
| | Closed | 89 | 7.03 | 177 | 3.7 | 309 | 136 | 7 |
| | Reservoir | 100 | 7.02 | 234 | 3.4 | 222 | 122 | 4 |
| 1B | Drainage | 799 | 6.96 | 317 | 4.0 | 289 | 163 | 3 |
| | Seepage | 58 | | ---------- Insufficient Sample Size ---------- | | | | |
| | Reservoir | 622 | 7.12 | 250 | 3.6 | 306 | 175 | 4 |
| 1C | Drainage | 1206 | 6.78 | 118 | 4.5 | 137 | 102 | 8 |
| | Seepage | 102 | 6.36 | 72 | 5.4 | 77 | 90 | 11 |
| | Closed | 105 | 6.92 | 130 | 4.4 | 164 | 106 | 4 |
| | Reservoir | 70 | 6.74 | 145 | 4.1 | 191 | 112 | 5 |
| 1D | Drainage | 690 | 6.77 | 136 | 3.9 | 161 | 129 | 4 |
| | Seepage | 167 | 6.47 | 69 | 3.0 | 82 | 134 | 3 |
| | Closed | 80 | 6.91 | 260 | 2.7 | 183 | 277 | 9 |
| | Reservoir | 381 | 6.96 | 256 | 4.5 | 280 | 165 | 3 |
| 1E | Drainage | 1386 | 6.92 | 151 | 5.2 | 147 | 73 | 9 |
| | Seepage | 41 | | ---------- Insufficient Sample Size ---------- | | | | |
| | Closed | 56 | | ---------- Insufficient Sample Size ---------- | | | | |
| | Reservoir | 43 | | ---------- Insufficient Sample Size ---------- | | | | |
| 1 | Drainage | 5072 | 6.84 | 145 | 4.4 | 164 | 108 | 7 |
| | Seepage | 478 | 6.51 | 84 | 4.0 | 112 | 111 | 5 |
| | Closed | 330 | 6.99 | 188 | 3.9 | [illegible] | 120 | 8 |
| | Reservoir | 1216 | 7.08 | 252 | 3.8 | 288 | 149 | 4 |
| 2A | Drainage | 1074 | 6.97 | 198 | 9.0 | 166 | 66 | 5 |
| | Seepage | 232 | 6.79 | 152 | 8.5 | 124 | 52 | 5 |
| | Closed | 119 | 6.74 | 122 | 10.7 | 113 | 58 | 14 |
| | Reservoir | 31 | | ---------- Insufficient Sample Size ---------- | | | | |
| 2B | Drainage | 539 | 7.38 | 651 | 8.3 | 458 | 84 | 5 |
| | Seepage | 396 | 6.49 | 87 | 4.8 | 111 | 67 | 7 |
| | Closed | 64 | 6.85 | 574 | 2.6 | 437 | 81 | 13 |
| | Reservoir | 52 | | ---------- Insufficient Sample Size ---------- | | | | |
| 2C | Drainage | 529 | 7.37 | 517 | 5.8 | 362 | 57 | 3 |
| | Seepage | 876 | 6.17 | 36 | 4.1 | 59 | 57 | 5 |
| | Closed | 60 | | ---------- Insufficient Sample Size ---------- | | | | |
| | Reservoir | 15 | | ---------- Insufficient Sample Size ---------- | | | | |
| 2D | Drainage | 2080 | 7.50 | 1224 | 9.4 | 760 | 53 | 4 |
| | Seepage | 2142 | 7.03 | 314 | 6.9 | 210 | 48 | 4 |
| | Closed | 208 | 6.74 | 94 | 6.0 | 91 | 34 | 4 |
| | Reservoir | 84 | | ---------- Insufficient Sample Size ---------- | | | | |
| 2 | Drainage | 4222 | 7.40 | 761 | 9.0 | 521 | 59 | 4 |
| | Seepage | 3646 | 6.76 | 120 | 6.1 | 107 | 53 | 4 |
| | Closed | 451 | 6.79 | 138 | 7.5 | 116 | 51 | 7 |
| | Reservoir | 182 | 6.96 | 181 | 8.1 | 108 | 32 | 2 |
| 3A | Drainage | 18 | | ---------- Insufficient Sample Size ---------- | | | | |
| | Closed | 7 | | ---------- Insufficient Sample Size ---------- | | | | |
| | Reservoir | 232 | 6.99 | 253 | 2.0 | 110 | 30 | 2 |
| 3B | Drainage | 452 | 6.82 | 190 | 10.2 | 313 | 127 | 4 |
| | Seepage | 1380 | 6.40 | 79 | 7.4 | 176 | 83 | 5 |
| | Closed | 265 | 6.48 | 68 | 7.8 | 203 | 109 | 6 |

Figure 5-29. Population estimates of lake numbers with ANC $\leq 200\ \mu eq\ L^{-1}$ by hydrologic type for all regions, Eastern Lake Survey-Phase I.



similar. Also, in-lake processes perhaps would exert a greater influence over chemistry in lakes with long hydraulic residence times.

A large, deep lake with a relatively small watershed would be expected to have a long (e.g., >3 yr) hydraulic residence time whereas a shallow lake with a large watershed would be expected to have a short (e.g., <0.5 yr) hydraulic residence time. Hydraulic residence time was approximated for the lakes in the ELS-I using the following expression:

$$RT = \frac{LA \times (Z_s \times 0.464)}{[RO \times (WA - LA)] + (LA \times PRECIP)}$$

where:
RT = hydraulic residence time (yr)
LA = lake area (ha), measured from USGS topographic maps
$Z_s$ = site depth (m), measured in the lake
RO = runoff (m/yr), interpolated from national runoff maps
WA = watershed area (ha), measured from USGS topographic maps
PRECIP = precipitation (m/yr), interpolated from National Weather Service data.

The numerator of the equation represents lake volume which was computed by multiplying lake area by mean depth, the latter of which was approximated by multiplying measured site depth by 0.464 (Wetzel 1983). This constant (0.464) for relating mean depth to maximum depth varies with the shape of a lake basin. Runoff was estimated for each lake's catchment (WA – LA) using a linear interpolation from mapped contours of mean annual runoff (Busby 1966). Precipitation at each lake was also interpolated from precipitation maps (Environmental Data Service 1983).

There are several potential sources of error in this estimation of hydraulic residence time (RT) in addition to errors associated with measurements of lake area, watershed area, and interpolation of runoff and precipitation. Site depth is used here as a surrogate for the deepest point in the lake, but not all lakes in this Survey were sampled at maximum depth. Failure to measure the maximum depth would cause the hydraulic residence time to be underestimated. Use of this approximation also assumes that lake volumes are at steady-state and that inflow and outflow are equal. Another assumption is that the topographic divide is coincident with the actual surface and groundwater divides. This assumption may be violated for lakes where contributing areas are independent of topographic boundaries, a problem that can be particularly severe for seepage lakes (Schnoor et al. 1985). For this reason, RT was not computed for seepage and closed lake types.

It was not possible to measure watershed boundaries accurately for many Florida lakes because the slight variations in topographic relief were undetectable on large-scale maps. In addition, large fluctuations in lake stage cause inlets and outlets for many Florida lakes to be ephemeral (Heath and Conover 1981) and result in unacceptable uncertainty in estimates for RT. Consequently, RT could not be computed effectively for lakes in Florida (3B).

The calculated RT for lakes in Regions 1 and 2, and Subregion 3A is shown in Table 5-14. Lakes in the Southern Blue Ridge (3A) have a short RT, a feature typical of reservoirs. Lakes in the Northeast exhibit estimated median RT values twice as high as those in Subregion 3A, yet, except for the $Q_4$ values of 1.03 yr in Subregion 1B, all quintiles shown for Region 1 are less than one year. The similarity in RT among the lakes in Region 1 suggests that variation in lake chemistry among these subregions may not be attributed to differences in RT. This does not exclude the possibility that chemical differences among lakes in Region 1 are related to hydrology. Flow paths from the watershed to the lakes may be important (Chen et al. 1984) but are not considered in this analysis.

The RT values for lakes in Region 1 contrast sharply with those in the Upper Midwest where $Q_4$ values for RT exceeded one year in all subregions. Recall that RT was not computed for seepage and closed lake types; these lake types account for approximately one-half of all lakes in the Upper Midwest. If it were possible to estimate the RT values for these lakes, many of which are probably much greater than one year (Lin and Schnoor 1985), the differences in RT between lakes in Regions 1 and 2 would be greater.

**Table 5-14. Estimated Hydraulic Residence Time for Drainage Lakes and Reservoirs by Subregion (Excludes Closed and Seepage Lakes), Eastern Lake Survey-Phase I**

| Subregion | Estimated Number of Drainage Lakes and Reservoirs | Hydraulic Residence Time (yr) | | |
|---|---|---|---|---|
| | | $Q_1$ | Median | $Q_4$ |
| 1A | 1091 | 0.06 | 0.23 | 0.58 |
| 1B | 1421 | 0.06 | 0.25 | 1.03 |
| 1C | 1276 | 0.04 | 0.17 | 0.59 |
| 1D | 1071 | 0.03 | 0.18 | 0.55 |
| 1E | 1429 | 0.05 | 0.23 | 0.75 |
| 1 | 6268 | 0.05 | 0.20 | 0.71 |
| 2A | 1105 | 0.15 | 0.65 | 2.31 |
| 2B | 591 | 0.03 | 0.25 | 1.47 |
| 2C | 544 | 0.15 | 0.77 | 1.82 |
| 2D | 2164 | 0.14 | 0.49 | 1.23 |
| 2 | 4404 | 0.13 | 0.48 | 1.62 |
| 3A | 250 | 0.03 | 0.10 | 0.32 |
| 3B | 452 | * | * | * |

*estimates not computed

The RT of selected populations of lakes among regions are compared in Table 5-15. Separate population estimates of RT were not computed in all regions for lakes with DOC $\leq 2$ mg $L^{-1}$, ANC $\leq 0$ $\mu$eq $L^{-1}$, and reservoirs because of insufficient sample size. Reservoirs constitute the primary lake type in Subregion 3A and most of these were clearwater lakes with DOC $\leq 2$ mg $L^{-1}$. Clearwater lakes in Regions 1 and 2 had RT

**Table 5-15. Population Estimates Based on Selected Characteristics and their Associated Hydraulic Residence Time, Eastern Lake Survey-Phase I**

| Region | Selected Population[a] | Estimated Number of Lakes | Hydraulic Residence Time (yr) | | |
|---|---|---|---|---|---|
| | | | $Q_1$ | Median | $Q_4$ |
| 1 | Clearwater[b] | 3972 | 0.08 | 0.31 | 1.02 |
| | Darkwater[c] | 2316 | 0.03 | 0.10 | 0.33 |
| | DOC $\leq 2$ | 445 | 0.09 | 0.50 | 1.30 |
| | DOC $\geq 6$ | 1691 | 0.03 | 0.09 | 0.29 |
| | ANC $\leq 0$ | 263 | 0.08 | 0.28 | 0.72 |
| | Reservoirs | 1216 | 0.04 | 0.14 | 0.38 |
| | Drainage | 5072 | 0.05 | 0.23 | 0.78 |
| 2 | Clearwater | 1601 | 0.41 | 1.14 | 3.54 |
| | Darkwater | 2803 | 0.07 | 0.36 | 1.20 |
| | DOC $\geq 6$ | 3065 | 0.12 | 0.39 | 1.22 |
| | Drainage | 4222 | 0.14 | 0.50 | 1.63 |
| 3A | Reservoirs | 232 | 0.03 | 0.11 | 0.31 |

[a] Unless stated otherwise, populations of drainage lakes and reservoirs are combined.
[b] Color ≤30 PCU
[c] Color >30 PCU

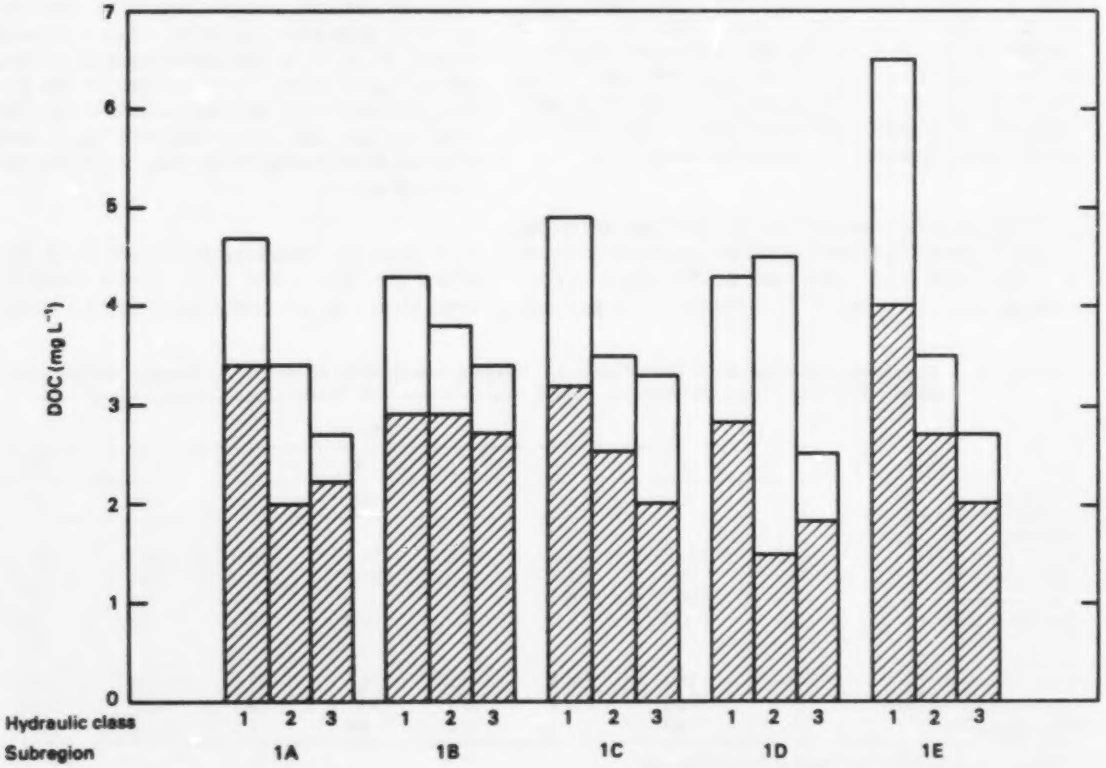
values approximately three times greater than darkwater lakes within the same region. The estimates of RT for low DOC and high DOC lakes parallel the estimates for the clearwater and darkwater lakes, respectively. The relationship between DOC and RT is addressed more fully later in this section. The RT values for the acidic lakes (ANC $\leq 0$ $\mu$eq $L^{-1}$) in Region 1 were approximately three times greater than the RT values for populations of darkwater and high DOC (DOC $\geq 6$ mg $L^{-1}$) lakes.

The estimated RT values for reservoirs in both Region 1 and Subregion 3A were very similar and were exceeded by all selected populations shown in Table 5-15 with the exception of the darkwater and high DOC lakes in Region 1. The RT values for drainage lakes in Region 2 were approximately 2 to 3 times greater than those for drainage lakes in Region 1. This can be attributed, in part, to the greater runoff and the higher watershed area:lake area ratio in Region 1.

The results presented in Table 5-15 suggest that there is a strong relationship between DOC (and related measures such as color) and RT. This relationship is further described in Figure 5-30, which shows the $Q_1$ and median for classes of RT plotted against DOC by subregion for the Northeast. The plot shows an inverse relationship between RT and DOC for all subregions in Region 1.

In Region 2, lakes with long RT also exhibit the lowest DOC, but the relationship was less variable for lakes with RT in the second class (0.5 - 1.0 yr). The inverse relationship between DOC and RT was evident in Subregion 3A, but the small concentrations of DOC (generally $\leq 2$ mg $L^{-1}$) in this subregion result in differences $<0.5$ mg $L^{-1}$ among the classes of RT. The lakes with short RT are generally shallow lakes with large watershed:lake area ratios. This is consistent with Gorham et al. (1985) who

Figure 5-30. Population estimates for median (top bar) and $Q_1$ (bottom bar) DOC by three classes of hydraulic residence time (<0.5, 0.5-1.0, and >1 yr, respectively) for lakes in the Northeast (Region 1), Eastern Lake Survey-Phase I.



observed an inverse relationship between color and maximum lake depth (after excluding lakes with drainage from peaty areas). They attributed this relationship to several factors: shallow lakes are more productive per unit volume than deep lakes with concomitant greater release of dissolved organic matter; this greater release of organic matter to the water column results in interaction with sediments and overlying water; evaporative concentration per unit volume is greater in shallow than in deep lakes; and residence times are likely shorter in shallow lakes allowing less photooxidation and microbial decomposition of dissolved organic matter. The data are not available from this Survey to address the first three factors, but they do support the importance of hydraulic residence time in influencing the DOC concentrations in lakes.

## 5.4 Characteristics of Acidic lakes

The estimated numbers of acidic lakes (ANC $\leq 0$ $\mu$eq L$^{-1}$) in most subregions were small with respect to the number required to characterize a population (Section 4.5.1). Acidic lakes were found in each subregion of the Northeast, although the number was small in Central New England (35) and Maine (8). Acidic lakes in the Upper Midwest occurred in the Upper Peninsula of Michigan (2B) and Northcentral Wisconsin (2C). No acidic lakes were sampled in the Southern Blue Ridge (3A), but 22 percent of the lakes in Florida (3B) were estimated to be acidic. The populations of acidic lakes were too small to characterize adequately for most subregions; therefore, the following discussion of acidic lakes is based on regional summaries.

The population estimates for selected variables in acidic lakes are summarized by region/subregion in Table 5-16. The estimated median sulfate concentration (124.7 $\mu$eq L$^{-1}$) in Region 1 is approximately twice as great as those in Region 2 (61.3 $\mu$eq L$^{-1}$) and Florida (3B) (58.8 $\mu$eq L$^{-1}$). The estimated SO$_4^{-2}$ concentrations for the acidic lakes in Region 1 differ little from the estimates for Subregion 1A (Section 4.8) where most of the acidic lakes in Region 1 are located. The sulfate concentrations for the acidic lakes in Region 2 differ little from the general population in the region, but the acidic lakes in Florida (3B) contain substantially lower concentrations of SO$_4^{-2}$ than the general population of Florida lakes.

The interquintile differences ($Q_d$) in sulfate concentrations for both Region 1 (39.8 $\mu$eq L$^{-1}$) and Region 2 (30.8 $\mu$eq L$^{-1}$) are relatively small, whereas the interquintile difference is 98.0 $\mu$eq L$^{-1}$ for acidic lakes in Florida. Calcium and extractable Al concentrations in Northeastern acidic lakes are also much greater than those in the Upper Midwest and Florida. The calcium concentrations in Region 1 acidic lakes are approximately 18 to 20 $\mu$eq L$^{-1}$ greater than those in Region 2. Over 50 percent of the acidic lakes in Region 1 have extractable Al concentrations exceeding 100 $\mu$g L$^{-1}$ whereas less than 3 percent and 12 percent of lakes in Region 2 and Subregion 3B, respectively, have concentrations exceeding 100 $\mu$g L$^{-1}$. The extractable Al concentrations in all three regions are generally an order of magnitude greater in acidic lakes compared to concentrations estimated for the general populations. The estimated DOC concentrations for the acidic lakes are low (approximately 50% of the concentrations estimated for the general populations) and, except for the $Q_1$ concentration in Region 2, concentrations are similar among regions. Low concentrations of DOC in acidic lakes suggest that most of these lakes are acidic because of mineral acidity.

The physical characteristics listed in Table 5-16 show that the acidic lakes have a smaller surface area than the general population of lakes (i.e., all

**Table 5-16.** Population Estimates of $Q_1$ (20th Percentile), Median, and $Q_4$ (80th Percentile) of Selected Variables for Acidic (ANC $\leq 0$ $\mu$eq L$^{-1}$) Lakes for Regions 1 and 2, and Subregion 3B, Eastern Lake Survey -Phase I

| | Region | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | 2 | | | 3B* | | |
| Variables | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ | $Q_1$ | M | $Q_4$ |
| *Primary* | | | | | | | | | |
| SO$_4^{-2}$ ($\mu$eq L$^{-1}$) | 104.6 | 124.7 | 144.4 | 48.5 | 61.3 | 79.4 | 29.3 | 58.8 | 127.3 |
| Ca$^{+2}$ ($\mu$eq L$^{-1}$) | 33.7 | 49.6 | 63.6 | 18.0 | 31.6 | 43.0 | 16.5 | 30.4 | 45.1 |
| Al, ext. ($\mu$g L$^{-1}$) | 44.8 | 105.3 | 216.2 | 9.2 | 21.8 | 46.7 | 0 | 10.7 | 73.9 |
| DOC (mg L$^{-1}$) | 0.6 | 2.1 | 5.0 | 2.0 | 2.9 | 5.1 | 0.6 | 2.8 | 5.1 |
| *Physical* | | | | | | | | | |
| Lake Area (ha) | 7.3 | 12.9 | 34.6 | 4.7 | 6.6 | 12.5 | 8.9 | 14.9 | 35.7 |
| Watershed Area (ha) | 58.0 | 146.3 | 442.2 | 24.4 | 48.1 | 129.4 | 46.9 | 123.6 | 220.3 |
| Site Depth (m) | 2.1 | 4.3 | 7.3 | 1.0 | 3.6 | 7.5 | 1.7 | 4.5 | 7.6 |

*No acidic lakes were sampled in Subregion 3A.

acidic and non-acidic lakes) in Region 1 (median 12.9 versus 16.7 ha), and Region 2 (median 6.6 versus 14.8 ha) and Subregion 3B (14.9 versus 17.3 ha) (Section 4.4). Estimated values for watershed area in acidic lakes are much smaller than those for the general population, which is consistent with an expected smaller watershed:lake area ratio.

The estimated site depth in acidic lakes for the Northeast differs little from the estimates for the general population. The acidic lakes in Region 2 are considerably shallower than the general population at all quintiles (median = 3.6 versus 5.6 m, respectively). In contrast, the acidic lakes in Subregion 3B are deeper than the general population (median = 4.5 versus 2.7, $Q_4$ = 7.6 versus 5.2 m, respectively).

## Section 6
## Regional and Subregional Characteristics

### 6.1 Northeast

Region 1, the Northeast, was estimated to contain several hundred acidic or low pH lakes (326 with ANC $\leq 0$ $\mu$eq $L^{-1}$, 240 with pH $\leq 5.0$), more than the Upper Midwest but not as many as Florida.[7] The Northeast was estimated to have more lakes than any other region with pH $\leq 6.0$ (916) or with ANC $\leq 50$ (1364) or $\leq 200$ $\mu$eq $L^{-1}$ (4258).

Concentrations of sodium and chloride increased toward the Atlantic Coast; at distances of more than 50 km from the coast concentrations were low, with an apparent increase within 20 km. Sodium, potassium and chloride concentrations in the Northeast were greater than in the Upper Midwest but less than in the Southeast. The Northeast had the highest median sulfate concentration (115.4 $\mu$eq $L^{-1}$) of all regions. The median calcium concentration (177.4 $\mu$eq $L^{-1}$) was lower than that in the Upper Midwest or Florida, and concentrations of magnesium were the lowest among the regions. However, only 5 percent of lakes in the Northeast had calcium $\leq 50$ $\mu$eq $L^{-1}$, which was the lowest percentage of lakes below this reference value for all regions. Unlike other regions, acidic lakes in the Northeast were characterized by high levels of extractable Al (for lakes with ANC $\leq 0$ $\mu$eq $L^{-1}$, the estimated median extractable Al was 105.3 $\mu$g $L^{-1}$ for the Northeast, 21.8 $\mu$g $L^{-1}$ in the Upper Midwest, and 10.7 $\mu$g $L^{-1}$ in Florida). Acidic lakes in the Northeast also had higher concentrations of calcium, magnesium and sulfate than acidic lakes in other regions.

The rank order of concentrations of major cations and anions in subregions of the Northeast at both the $Q_1$ and median population values were discussed in Section 5.2.5.2 (Table 5-5). In Subregion 1D, $Na^+$ was the dominant cation. In Subregions 1A, 1B, and 1C, $SO_4^{-2}$ was the dominant anion at $Q_1$; at the median value, however, $SO_4^{-2}$ was dominant only in Subregion 1A, with $HCO_3^-$ dominant in Subregions 1B, 1C and 1E. Chloride dominated at both estimated values in Subregion 1D. Using the mean from 79 lakes in New England, Brooks and Deevey (1963) found a rank order of $HCO_3^- > SO_4^{-2} > Cl^-$ and observed that most of the lakes were bicarbonate systems.

When unmeasured anion concentrations ($A^-$; Table 5-6) were included as a measure of organic anion, the rank order of anions changed little (Section 5.2.5.2, Table 5-6) in Region 1. At $Q_1$ levels, the anion deficit was zero for Subregions 1A, 1B and 1D. Anion deficit was only fourth in importance in Subregion 1C and third in Subregion 1E after bicarbonate and sulfate. At median values, the anion deficit was also zero in Subregion 1D. It was fourth in Subregions 1B and 1C and third in Subregions 1A ($SO_4^{-2} > HCO_3^- > A^-$) and 1E ($HCO_3^- > SO_4^{-2} > A^-$).

Medians and interquintile differences ($Q_4 - Q_1 = Q_d$) are given for several variables in Table 6-1. The interquintile difference ($Q_d$) is a measure of the variability of chemistry among lakes within subregions. For ANC, calcium, and sulfate, Maine (1E) showed less variability than the other subregions in the Northeast, and the Poconos/Catskills (1B) showed the greatest variability.

The Northeast was the only region where most lakes (65%) were clearwater ($\leq 30$ PCU). Dissolved organic carbon concentrations in darkwater ($>30$ PCU) northeastern lakes were much lower than those in darkwater lakes in the Upper Midwest or Florida. Total phosphorus and silica concentrations were higher in darkwater lakes than in clearwater lakes. Darkwater lakes were also shallower and smaller, but their watershed areas were often larger than those of clearwater lakes.

Seepage lakes were not common in the Northeast, representing only 7 percent of the lakes classified by hydrologic type. Drainage lakes, 71 percent of the total, were the most common hydrologic type, followed by reservoirs (17%). Seepage lakes generally had the lowest values of ANC and pH of any lake type. The median ANC for seepage lakes was 84 $\mu$eq $L^{-1}$ versus 145 $\mu$eq $L^{-1}$ for drainage lakes. In seepage lakes the median pH was 6.5 and in drainage lakes, 6.8. These observations of lower

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[7] All references to medians, quintiles, percentages, numbers, or areas are population estimates but are not always noted as estimates in the text. Upper confidence limit information is provided in the tables but is not discussed in the text.

**Table 6-1.** **Medians and Interquintile Differences ($Q_4 - Q_1 = Q_d$) for pH, ANC, Calcium, Sulfate, and DOC, Eastern Lake Survey-Phase I**

| Region and Subregion | pH | | ANC | | $Ca^{+2}$ | | $SO_4^{-2}$ | | DOC | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Median | $Q_d$ | Median | $Q_d$ | Median | $Q_d$ | Median | $Q_d$ | Median | $Q_d$ |
| 1A | 6.71 | 1.66 | 111.8 | 236.8 | 144 | 201 | 119 | 38 | 4.1 | 3.0 |
| 1B | 7.02 | 0.72 | 297.4 | 428.3 | 291 | 344 | 159 | 103 | 3.8 | 3.1 |
| 1C | 6.77 | 1.00 | 119.9 | 335.7 | 137 | 314 | 101 | 58 | 4.4 | 3.8 |
| 1D | 6.81 | 0.93 | 161.8 | 363.2 | 187 | 296 | 141 | 82 | 4.0 | 4.5 |
| 1E | 6.91 | 0.74 | 148.4 | 226.3 | 147 | 191 | 75 | 31 | 5.2 | 5.5 |
| 1 | 6.87 | 0.93 | 158.1 | 348.3 | 177 | 293 | 115 | 86 | 4.3 | 3.8 |
| 2A | 6.94 | 0.77 | 184.9 | 305.2 | 143 | 232 | 62 | 37 | 9.2 | 7.2 |
| 2B | 7.10 | 1.75 | 283.6 | 1228.9 | 246 | 883 | 78 | 54 | 6.8 | 7.8 |
| 2C | 6.68 | 1.72 | 93.9 | 584.9 | 101 | 346 | 57 | 34 | 4.6 | 4.9 |
| 2D | 7.39 | 1.44 | 801.7 | 1917.9 | 522 | 1102 | 50 | 56 | 8.8 | 7.8 |
| 2 | 7.09 | 1.46 | 359.5 | 1336.7 | 238 | 856 | 57 | 53 | 7.5 | 7.7 |
| 3A | 6.98 | 0.56 | 250.2 | 272.2 | 105 | 184 | 32 | 40 | 1.9 | 2.8 |
| 3B | 6.56 | 2.03 | 83.5 | 720.5 | 238 | 799 | 94 | 244 | 8.6 | 9.6 |

ANC and pH in seepage lakes in Region 1 are consistent with the pattern found in the Upper Midwest.

Nutrient concentrations were low for most of the lakes in the Northeast. Median concentrations were estimated to be 0.4 $\mu eq\ L^{-1}$ nitrate, 1.4 $\mu eq\ L^{-1}$ ammonium and 9.0 $\mu g\ L^{-1}$ total phosphorus. True color values were similar among subregions, and turbidity was generally low, resulting in a median Secchi disk transparency of 2.3 m. DIC values were low (2.1 mg $L^{-1}$ estimated median).

### *6.1.1 Adirondacks (1A)*

The Adirondacks contained the highest percentage and number of acidic lakes (ANC $\leq 0\ \mu eq\ L^{-1}$) and lakes with pH $\leq 5.0$, of any subregion except Florida (3B). A total of 138 lakes, representing 11 percent of the target population, was estimated to have ANC $\leq 0\ \mu eq\ L^{-1}$. A similar number of lakes (128) was estimated to have pH values $\leq 5.0$. Compared with other areas in the Northeast, Subregion 1A had higher percentages and numbers of lakes with ANC values $\leq 50\ \mu eq\ L^{-1}$ (36% or 459 lakes) and pH $\leq 6.0$ (27% or 343 lakes).

Far more lakes (82) in the Adirondacks, classified as clearwater ($\leq 30$ PCU), had extractable aluminum concentrations $\geq 150\ \mu eq\ L^{-1}$ than any other subregion sampled as part of the ELS-I. Only 26 such lakes occurred in all other subregions combined. Other studies have also found elevated aluminum associated with low pH in Adirondack lakes (Driscoll et al. 1980, Schofield 1976, 1982).

The median sulfate concentration in Subregion 1A was 118.7 $\mu eq\ L^{-1}$. This value was lower than those observed in Southern New England (1D) and the Poconos/Catskills (1B), but was higher than in Central New England (1C) and Maine (1E). Thirteen percent of the lakes in the Adirondacks had sulfate concentrations $\geq 150\ \mu eq\ L^{-1}$ compared to 56 percent in 1B and 46 percent in 1D. The population estimates for the concentrations of sulfate in Subregion 1A are similar to results of a survey of 214 high elevation lakes in the Adirondacks done by Schofield (1976) in 1975. The mean sulfate concentration for that survey was 133 $\mu eq\ L^{-1}$. The Adirondacks contained the largest surface area of lakes with high sulfate in the Northeast. This is because several large lakes in the western portion of this subregion had high sulfate concentrations.

Sodium and chloride concentrations in the Adirondacks were the lowest in the Northeast. This subregion also had the lowest first quintile magnesium concentration in the Northeast. In the Adirondacks, calcium was the dominant cation and sulfate was the dominant anion. The rank order of ions observed in ELS-I was consistent with other observations for the area (Peters et al. 1981, Schofield 1982).

Specific subpopulations were analyzed for the eastern and western areas of the Adirondacks, using lakes located on either side of a meridian of 74° 30′ 00″. Whereas sulfate concentrations were the same on the western (windward) and eastern (leeward) areas of the Adirondack drainage divide, lakewater pH, ANC and calcium were estimated to be lower in the west. Median ANC was 39.3 $\mu eq\ L^{-1}$ west of the divide and 166.7 $\mu eq\ L^{-1}$ east of the divide. Median calcium was 101.9 $\mu eq\ L^{-1}$ and pH was 6.15 on the west side as compared to 202.5 $\mu eq\ L^{-1}$ and 6.88, respectively, on the east side. The percentage of lakes with calcium $\leq 50$ μeq $L^{-1}$ was 12.5 percent versus 4.0 percent on the west and east sides, respectively. Correspondingly, median extractable aluminum was also higher on the windward side (12 versus 5 μg $L^{-1}$). Dissolved organic carbon concentrations were similar in both areas ($Q_1 = 2.4$ mg $L^{-1}$ in the west and 2.9 mg $L^{-1}$ in the east, median = 4.3 mg $L^{-1}$ in the west and 3.9 mg $L^{-1}$ in the east). Consequently, even though sulfate concentrations were the same on both sides, the lower values of calcium at all quintiles on the west side resulted in more acidic lakes.

Population estimates for lakes having ANC $\leq 0$ μeq $L^{-1}$ were significantly higher on the west side (20%, 130) than on the east side (1.3%, 8). Similar estimates were obtained using pH $\leq 5.0$ as a reference value (120 in the west and 8 in the east). The proportion of lakes with calcium $\leq 50$ μeq $L^{-1}$ also varied (12.5% in the west and 4.1% in the east). Only 1.3 percent of the lakes on the east side were estimated to have extractable aluminum $\geq 50$ μg $L^{-1}$, whereas 29 percent of the lakes on the west side had values $\geq 50$ μg $L^{-1}$ and 17 percent had values $\geq 150$ μg $L^{-1}$. Values of total aluminum were also high in the Adirondacks. In addition, both pH and ANC were negatively correlated with elevation in the Adirondacks. This relationship was not observed in any other area in the Northeast. Likewise, Haines and Akielaszek (1983) found only a weak relationship between elevation and ANC in clearwater, headwater lakes in New England.

Most of the lakes in the Adirondacks were clearwater. Lakes that had pH values $\leq 5.0$ were equally likely to be darkwater (34%) as were those with higher pH. Dissolved organic carbon concentrations in darkwater lakes were relatively low compared to other areas; only 39 percent of the darkwater systems had DOC $\geq 6$ mg $L^{-1}$. Darkwater lakes in the Adirondacks tended to be smaller, but had larger relative watershed areas than the clearwater lakes. The watershed area:lake area ratios were about 20 for darkwater, and 10 for clearwater systems.

Total phosphorus in the Adirondacks was the lowest in the Northeast ($Q_1 = 1.6$ μg $L^{-1}$, $M = 4.7$ μg $L^{-1}$). Together with low true color and DOC, this resulted in the highest Secchi disk transparencies in the Northeast ($M = 2.8$ m, $Q_4 = 4.9$ m).

Drainage lakes were the most common lake type. This hydrologic type was estimated to represent 77 percent of the population. Drainage lakes were characterized by low ANC and pH values as well as the highest extractable aluminum concentrations.

It is important to point out that the Adirondacks contain many lakes <4 ha in size, as do some other areas. Lakes <4 ha were not included on all small-scale maps used for ELS-I lake selection; therefore, in developing the frame population, it was necessary to exclude lakes <4 ha from sampling to establish consistency and reliability in estimating the target population. The chemical status of lakes <4 ha is unknown from the ELS-I data, but lakes <4 ha are being sampled by the Adirondack Lake Survey Corporation (ALSC; Colquhoun et al. 1984). Results from ELS-I cannot be extrapolated to lakes smaller than 4 ha and their chemistry cannot be inferred from ELS-I measurements on larger lakes. Comparison of the chemistry of ALSC lakes <4 ha to ELS-I lakes in the Adirondacks would provide insight into the importance of small lakes in estimating the proportion of acidic and low pH lakes in the total population of lakes in the Adirondacks.

### *6.1.2 Poconos and Catskills (1B)*

The Poconos/Catskills contained few low pH lakes or acidic lakes. Twelve lakes (1%) were estimated to have pH values $\leq 5.0$ and 78 lakes (5%) had ANC $\leq 0$ μeq $L^{-1}$. In contrast to other areas surveyed, acidic lakes were larger than non-acidic lakes. As a result, when the area of acidic lakes is compared to other subregions, the Poconos/Catskills contain the largest surface area of acidic lakes in the Northeast (2937 ha). This subregion had 116 lakes with pH $\leq 6.0$ and 194 lakes with ANC $\leq 50$ μeq $L^{-1}$. It was, however, the only part of the Northeast where less than half of the lakes had ANC values $\leq 200$ μeq $L^{-1}$. Median calcium concentrations in Subregion 1B were the highest in the Northeast. Magnesium concentrations were also high. Sulfate concentrations in the Poconos/Catskills were very high. Median and $Q_1$ sulfate concentrations were the highest in the region ($Q_1 = 118.1$ μeq $L^{-1}$, $M = 159.3$ μeq $L^{-1}$). Few of the lakes had sulfate concentrations <50 μeq $L^{-1}$. Similarly high concentrations of sulfate were found by Bradt and Berg (1983) and Bradt et al. (1984). The fourth quintile value for extractable aluminum in Subregion 1B was the lowest of all subregions in the Northeast, as was total aluminum. Silica concentrations were low, but nutrients were the highest in the Northeast. Lakes in the Poconos/Catskills were clearly different in nearly all aspects from other areas of the Northeast. Reservoirs were common (42%) and the median watershed area was 169 ha.

### *6.1.3 Central New England (1C)*

Few acidic or low pH lakes were found in Central New England (an estimated 2 percent or 25 lakes with pH $\leq 5.0$, 35 with ANC $\leq 0$ μeq $L^{-1}$). Smaller lakes were generally more acidic. No clearwater lakes had extractable aluminum concentrations $\geq 100$ μeq $L^{-1}$. Shallow lakes in Central New England generally had higher ANC than deep lakes. Central New England had 191 lakes with pH $\leq 6.0$

and 262 lakes with ANC ≤50 μeq $L^{-1}$. This subregion also had the second highest percentage of number (68%) and the highest percentage of area (74%) of lakes with ANC ≤200 μeq $L^{-1}$ in the Northeast. Subregion 1C had few (63) lakes with calcium concentrations ≤50 μeq $L^{-1}$, but the lowest median calcium concentration (136.8 μeq $L^{-1}$) in the Northeast.

Most of the lakes (68%) in Central New England were clearwater, with high Secchi disk transparencies. Unlike other northeastern subregions, darkwater lakes in Central New England had median and quintile pH and ANC values that were lower than those for clearwater lakes. Central New England lakes were predominantly drainage lakes (81%). The seepage lakes, representing 7 percent of the lakes in this subregion, generally had lower ANC and pH and higher extractable aluminum than drainage lakes. This was also similar to observations in Subregion 2C.

Within the subregion, marked differences were noted between lakes in Vermont and New Hampshire. None of the lakes in Vermont was estimated to have ANC ≤0 μeq $L^{-1}$, but 17 lakes in New Hampshire were estimated to have ANC ≤0 μeq $L^{-1}$. Also, many more lakes in New Hampshire (537) were estimated to have ANC ≤200 μeq $L^{-1}$ than in Vermont (90). This is consistent with maps of bedrock geology (Norton 1982, Hendrey et al. 1980b), descriptions of geologic substrates by Brooks and Deevey (1963) and mapping of lake alkalinities by Clarkson (1982). Lakes with lower ANC values were clustered in northern and southern Vermont, with higher ANC lakes in the remainder of the state. Lakes with higher values of ANC were found particularly in the Champlain Lowland. A similar pattern was noted by Haines and Akielaszek (1983). Norton et al. (1981) also observed clearwater, low ANC lakes in New Hampshire. In contrast to Vermont, low ANC (≤50 μeq $L^{-1}$) lakes were distributed throughout New Hampshire, and as noted, New Hampshire was estimated to have many more lakes with ANC ≤200 μeq $L^{-1}$ than Vermont. Lakes with ANC ≤200 μeq $L^{-1}$ were clustered in southeastern New Hampshire and along the border with Vermont (Section 4.5.1.2, Figure 4-11).

### 6.1.4 Southern New England (1D)

Five percent of the lakes in Southern New England were acidic and 5 percent had low pH (66 lakes with ANC ≤0 μeq $L^{-1}$, 66 lakes with pH ≤5.0). Although both pH and ANC showed positive relationships with lake size, this subregion contained the largest lake area with low pH in the Northeast (6% or 2295 ha with pH ≤5.0). Southern New England had 192 lakes with pH ≤6.0, 284 with ANC ≤50 μeq $L^{-1}$, and 755 with ANC ≤200 μeq $L^{-1}$. Lakes with low ANC were not distributed uniformly, with higher values found in southern Connecticut and parts of Massachusetts (Section 4.5.1.2, Figure 4-11).

Concentrations of sulfate were the second highest in the Northeast, with a median value of 141.1 μeq $L^{-1}$. Subregion 1D contained more lakes (133) with calcium ≤50 μeq $L^{-1}$ than any other northeastern subregion. Median sodium and chloride concentrations in Southern New England were the highest of any subregion, and median potassium and magnesium concentrations were the highest in the Northeast. High sea-salt contributions were also observed by Haines and Akielaszek (1983), who observed a similar decline in chloride concentrations with distance from the coast.

The majority (62%) of Southern New England lakes were clearwater. Southern New England had a much higher percentage (18%) of lakes with low DOC concentrations (≤2 mg $L^{-1}$) than any other northeastern subregion. Unlike other subregions of the Northeast, darkwater lakes had much higher calcium concentrations than clearwater lakes.

Drainage lakes were predominant (52%) in Southern New England, although reservoirs were also important (29%). Seepage lakes generally had the lowest pH and ANC of any lake type although they comprised only 13 percent of the lake population. Closed lakes had the highest median extractable aluminum concentration. Lakes in Southern New England showed the greatest variation in elevation of any subregion in the Northeast ($Q_4 - Q_1 = 567$ m) and were also the shallowest ($Q_4 = 5.9$ m) of any subregion except Florida. Subregion 1D contained the most small watersheds in the Northeast ($Q_1 = 65$ ha). Silica concentrations in this subregion were relatively high for the Northeast (M = 2.1 mg $L^{-1}$), but variable ($Q_d = 4.3$). Phosphorus concentrations were also relatively high compared to other subregions (M = 14.0 μg $L^{-1}$), similar to values reported by Deevey (1940) for Connecticut (M = 14.9 μg $L^{-1}$).

### 6.1.5 Maine (1E)

Maine had the fewest acidic or low pH lakes in the Northeast. Only one half of one percent of the lakes had pH ≤5.0 or ANC ≤0 μeq $L^{-1}$. Maine also had the fewest lakes with pH ≤6.0 (5%) or ANC ≤50 μeq $L^{-1}$ (11%). However, Maine had the most lakes with ANC ≤200 μeq $L^{-1}$ (1020 or 67%) in the Northeast, comprising 109,546 ha. Shallow lakes generally had higher ANC than did deeper lakes. Lakes with ANC ≤200 μeq $L^{-1}$ were found throughout Maine (Section 4.5.1.2, Figure 4-11). ANC values >200 μeq $L^{-1}$ were found in several areas, but principally in the northern third of the state. The spatial distribution of lakes with high ANC was similar to that found by Mairs (1966) and Haines and Akielaszek (1983).

Maine lakes had calcium concentrations that were intermediate in the Northeast. None of the clearwater lakes sampled in Maine had extractable aluminum $\geq 50\ \mu g\ L^{-1}$, in sharp contrast to the Adirondacks, where 14 percent had extractable aluminum $\geq 50\ \mu g\ L^{-1}$. Maine had the lowest median sulfate in the Northeast (74.6 $\mu eq\ L^{-1}$). Only one percent of the lakes in Maine had sulfate concentrations $\geq 150\ \mu eq\ L^{-1}$. Other surveys have also found lower sulfate values in Maine than in other areas of the Northeast (Norton et al. 1981, Haines and Akielaszek 1983). Maine was the only area in the Northeast where $HCO_3^- > SO_4^{-2}$ at $Q_1$ levels. Chloride concentrations declined sharply with distance from the coast, as other studies (Mairs 1967, Haines and Akielaszek 1983, Norton et al. 1981) have shown. Concentrations of calcium were higher than those of other cations.

Maine contained the lowest percentage of clearwater lakes (55%) and had a much higher percentage (42%) of lakes with DOC $\geq 6$ mg $L^{-1}$ than any other northeastern subregion. Others have noted the significant number of lakes with perceptible color (Davis et al. 1978b). Maine was unique in the Northeast in having darkwater lakes with higher ANC concentrations than clearwater lakes for the median and quintile values. As in the Adirondacks, darkwater lakes in Maine generally were smaller but had larger watersheds than clearwater lakes (median WA:LA was 23 for darkwater lakes, 9 for clearwater lakes). Darkwater lakes in Maine also were shallower than clearwater lakes. Darkwater lakes had high DOC concentrations, similar to observations in the Upper Midwest and Florida.

Maine had the highest percentage of drainage lakes in the Northeast (91%). The largest median lake area (29.1 ha), and watershed area (472 ha), and some of the deepest lakes ($Q_4$ = 10.6 m) also were found in Maine. Nutrient concentrations were low (estimated median total phosphorous = 5.7 $\mu g\ L^{-1}$) and Secchi disk transparency values high (M = 2.6 m, $Q_4$ = 4.7 m), consistent with other investigations (Cooper 1942, Bailey 1975, Davis et al. 1978b).

## 6.2 Upper Midwest

The Upper Midwest shows considerable heterogeneity in lake chemistry within subregions (Table 6-1) and major differences in chemical and physical characteristics of lakes among subregions. As an example, lakes in Subregions 2B and 2D exhibited the largest interquintile differences ($Q_d$) for ANC and calcium. Interquintile differences for the other variables were exceeded only by those in Subregion 3B. The contrasts within Region 2 are evident by comparing the low ANC lakes of Northcentral Wisconsin (M = 93.9 $\mu eq\ L^{-1}$) with those of the Upper Great Lakes Area (M = 801.7 $\mu eq\ L^{-1}$).

The Upper Midwest was estimated to have only 148 lakes with ANC $\leq 0\ \mu eq\ L^{-1}$, far fewer than the estimate for the Northeast and Subregion 3B. However, the estimated number of lakes with ANC $\leq 50\ \mu eq\ L^{-1}$ in Region 2 (1312) was comparable to that in Region 1 (1364) and nearly twice as great as in Subregion 3B (742).

Lakes in Region 2 were characterized by low concentrations of many constituents including extractable aluminum, sodium, sulfate and chloride. Dissolved organic carbon concentrations in Region 2 (M = 7.5 mg $L^{-1}$) were almost twice as high as those in Region 1 (M = 4.3 mg $L^{-1}$); an estimated 63 percent of the lakes had DOC concentrations $\geq 6$ mg $L^{-1}$.

The order of major cations in the Upper Midwest was typical of ion orders observed in other calcium bicarbonate lakes. The order of major anions at the median was generally typical of bicarbonate lakes ($HCO_3^- > SO_4^{-2} > Cl^-$) although lakes in Subregions 2B and 2C had relatively high concentrations of sulfate at $Q_1$. Including organic anions (calculated from the anion deficit) in the order of anions illustrated the potentially important influence of organic anions on lake chemistry in the Upper Midwest (Section 5.2.5.2, Table 5-6).

### *6.2.1 Northeastern Minnesota (2A)*

Most of the lakes in Northeastern Minnesota had relatively high ANC and pH. No acidic (ANC $\leq 0\ \mu eq\ L^{-1}$) lakes were sampled in Subregion 2A, a finding consistent with the results of a sampling of 290 Northeastern Minnesota lakes reported by Schnoor et al. (1986). Only 1 percent of the lakes in the subregion were estimated to have a pH $\leq 6.0$. Calcium concentrations were also high; the $Q_1$ value for this variable was the highest in the Upper Midwest. Sulfate concentrations were low in Northeastern Minnesota lakes ($Q_4$ = 83.9 $\mu eq\ L^{-1}$), but were intermediate compared to other subregions in the Upper Midwest.

The most striking feature of the lakes in Northeastern Minnesota was their high color (70% are considered darkwater) and DOC (76% of the lakes have DOC $\geq 6$ mg $L^{-1}$) values. This apparently results from the extensive peatland and the connected drainage lake networks (74% of the lakes are drainage) (Rapp et al. 1985; Omernik and Griffith 1985). The WA:LA ratio for darkwater lakes in Subregion 2A was 13.3, but this variable alone is insufficient to explain the high color and high DOC in these lakes.

The lake chemistry in Northeastern Minnesota showed relatively little heterogeneity. For example, the $Q_d$ for pH in Subregion 2A was 0.77 pH units compared to 1.75, 1.72 and 1.44 for Subregions 2B, 2C and 2D, respectively (Table 6-1). A similar pattern was observed for ANC where $Q_d$ was 305.2 for Subregion 2A and 1228.9, 584.9 and 1917.9 for Subregions 2B, 2C and 2D, respectively.

The lakes in Northeastern Minnesota had slightly larger lake surface and watershed areas than other lakes in the Upper Midwest, but the WA:LA ratios were not substantially greater than those of other subregions. Consequently, the higher ANC concentrations in the Northeastern Minnesota lakes may be attributed, in part, to the composition of the surficial and bedrock geology. Other studies of lake chemistry and watershed factors in Minnesota (most of these studies extending beyond the boundaries of Subregion 2A) show an association between soils (Gorham et al. 1983), glacial till (Moyle 1956) and bedrock geology (Rapp et al. 1985). However, Winter (1977) considered groundwater chemistry to be a better index of lake chemistry because it incorporates hydrology with the geology. The moderately high sulfate concentrations in Northeastern Minnesota lakes are also likely to result from the presence of sulfide ores in the watershed (Rapp et al. 1985). The extractable aluminum concentrations in clearwater lakes for Subregion 2A were low, and none of the lakes sampled had values ≥100 µg L$^{-1}$. Most of the lakes with high aluminum values in Subregion 2A also had high DOC. It is assumed that most of the extractable aluminum in this case is complexed with organic ligands (Driscoll et al. 1980).

### *6.2.2 Upper Peninsula of Michigan (2B)*

The Upper Peninsula of Michigan was estimated to have the highest percentage of acidic lakes (10%) in the Upper Midwest. An estimated nine percent of the lakes in this subregion had pH ≤5, also the highest percentage in the Upper Midwest. However, because there is a relatively large population of high ANC lakes in Subregion 2B, median values for pH (7.10) and ANC (283.6 µeq L$^{-1}$) are high relative to other subregions. The acidic lakes (ANC ≤0 µeq L$^{-1}$) in Subregion 2B were generally clearwater (median color = 22 PCU). Thirty-eight percent of the lakes in Subregion 2B were seepage lakes with very low concentrations of most ions (median $Ca^{+2}$ = 111 µeq L$^{-1}$; $SO_4^{-2}$ = 67 µeq L$^{-1}$). Drainage lakes comprised 51 percent of the lake type. Sulfate concentrations were low ($Q_4$ = 103.5 µeq L$^{-1}$) in Subregion 2B compared to lakes in Region 1, but they were approximately 20 percent greater than in other subregions in Region 2. Silica concentrations were extremely low ($Q_1$ for silica in Subregion 2B lakes was 0.3 mg L$^{-1}$). The extractable aluminum values were generally low (only 0.4% of the clearwater lakes had values ≥100 µg L$^{-1}$), although the $Q_4$ value of 11.9 µg L$^{-1}$ was relatively high. Large interquintile differences for all primary variables except sulfate were observed. This heterogeneity in Subregion 2B can be explained by the contrasting chemical composition of the bedrock types and the presence of high percentages of both seepage (38%) and drainage (51%) lakes (Schnoor et al. 1986). Subregion 2B also represents a large geographic area, extending approximately 250 km from east to west, and exhibits a considerable gradient in deposition chemistry (Glass and Loucks 1986). The greater numbers of low ANC lakes observed in the eastern portion of the peninsula (Section 4.5.1.3, Figure 4-12) are consistent with the pattern observed by Schneider (1975). The number of acidic lakes in the eastern portion (east of longitude 87°) of the Upper Peninsula of Michigan was estimated to be 18.2 percent, which also agrees with the estimate of 19 percent by Schnoor et al. (1986).

### *6.2.3 Northcentral Wisconsin (2C)*

Northcentral Wisconsin, although comprising the smallest land surface area of all subregions, had an estimated target population of 1480 lakes, excluding those >2000 ha. Whereas only a small percentage (3%) were estimated to be acidic (ANC ≤0 µeq L$^{-1}$), Subregion 2C had the highest percentage (41%) of lakes among all subregions with ANC ≤50 µeq L$^{-1}$. These results agree closely with the findings of Eilers et al. (1983) and Schnoor et al. (1985) who reported 3 percent and 4 percent, respectively, of lakes in this area with ANC ≤0 µeq L$^{-1}$. The median ANC for lakes in Northcentral Wisconsin (93.9 µeq L$^{-1}$) was the lowest among all subregions except Florida (83.5 µeq L$^{-1}$).

The factors believed to contribute most to the low ionic concentrations of lakes in Northcentral Wisconsin are hydrology (Juday et al. 1935, Broughton 1941, Eilers et al. 1983, Lin and Schnoor 1986), soils (Gorham et al. 1983), and composition of the glacial till (Simpkins et al. 1978). Seepage and drainage lakes exhibited markedly different chemistry. The median WA:LA ratio for lakes in Subregion 2C (6.1) was lower than for other lakes in the Upper Midwest and most other lakes in the Survey (with the exception of Subregion 3B, 5.5). The modest influence of watershed factors results in low weathering rates reflected in low concentrations of silica and calcium (Schnoor et al. 1986). The acidic lakes in Northcentral Wisconsin are similar in many chemical aspects and physical features to those in the Upper Peninsula of Michigan and Florida (i.e., clearwater, low ionic concentration, seepage lakes).

### *6.2.4 Upper Great Lakes Area (2D)*

No acidic (ANC ≤0 µeq L$^{-1}$) lakes were sampled in the Upper Great Lakes Area. The subregion had a median ANC of 801.7 µeq L$^{-1}$, by far the highest among all subregions. It also contained the largest number of lakes (1411) with ANC $\leq 200$ $\mu$eq L$^{-1}$ of any subregion. An estimated 20 percent of the lakes had pH values >8.07; 4 percent of the lakes had pH values $\leq 6.0$. The proportion of clearwater and darkwater lakes in Subregion 2D was approximately equal. Lakes in Subregion 2D contained high concentrations of many major ions (Sections 4.7 and 4.8, Tables 4-25 through 4-30), but the concentration of extractable aluminum was relatively low in clearwater lakes ($Q_4 = 8.2$ $\mu$eq L$^{-1}$).

Most of the lakes in Subregion 2D with ANC $\leq 50$ $\mu$eq L$^{-1}$ are located in Northwestern Wisconisn (Section 4.5.1.3, Figure 4-12). This agrees with the expected pattern based on Omernik and Griffith (1985) and a survey by Lillie and Mason (1983).

Subregion 2D contains at least three distinct geological provinces that result in strongly contrasting chemistry among lakes in Minnesota, Wisconsin and Michigan. The Minnesota portion of Subregion 2D was described by Moyle (1956) as a "hard-water flora" area, which was attributed, in part, to the presence of Paleozoic and Cretaceous sedimentary rocks. Carbonate in glacial till (Brugam 1981) and the soils (Gorham et al. 1983) in this part of Minnesota may also contribute to high concentrations of calcium carbonate in these lakes. The lower peninsula of Michigan, also contained within Subregion 2D, is underlain by Cretaceous sedimentary carbonate rocks (Barr 1978); consequently, lakes in this area also had high values of ANC. High ANC values in lower Michigan are in agreement with the study by Schneider (1975). In contrast, the Wisconsin portion of 2D is underlain by sedimentary sandstones and igneous bedrock (Mudrey et al. 1982) and covered by 20 to 200 m of glacial till containing a small percentage of carbonate till (Hadley and Pelham 1976).

## 6.3 Southeast

Region 3, the Southeast, contains only two subregions. As mentioned previously, these two disjunct subregions contain lakes that are extremely different in physical and chemical characteristics and will be discussed separately.

### *6.3.1 Southern Blue Ridge (3A)*

No acidic or low pH lakes were sampled in the Southern Blue Ridge. This subregion had the lowest percentage of lakes with ANC $\leq 50$ $\mu$eq L$^{-1}$ (1%) or pH $\leq 6.0$ (<1%) of any subregion. It also contained the second lowest percentage of lakes for any subregion with ANC $\leq 200$ $\mu$eq L$^{-1}$ (34%). ANC and pH values were generally lowest in the large, deep lakes.

The Southern Blue Ridge had the lowest median sulfate concentration (31.8 $\mu$eq L$^{-1}$) and the second lowest median calcium concentration (104.7 $\mu$eq L$^{-1}$) of any subregion. No clearwater lakes with extractable aluminum concentrations $\geq 50$ $\mu$g L$^{-1}$ were sampled.

The majority of the lakes in the Southern Blue Ridge were classified as darkwater (55%), but an evaluation of DOC and anion deficit indicates that the color is not related to organic matter. Apparently inorganic contributions to color were important in these lakes; only 11 percent of the darkwater lakes had DOC $\geq 6$ mg L$^{-1}$, which was far less than in any other subregion. Southern Blue Ridge lakes had the lowest DOC concentrations of any subregion (54% had DOC $\leq 2$ mg L$^{-1}$ and only 6% had DOC $\geq 6$ mg L$^{-1}$). Darkwater lakes in the Southern Blue Ridge had smaller median lake and watershed areas than clearwater lakes but were similar in other characteristics.

An estimated 90 percent of the lakes were reservoirs. As is typical for reservoirs, lakes in this subregion had the largest median watershed area (682 ha), smallest median lake area (10.8 ha) and the highest median turbidity (3.9 NTU) of any subregion (Thorton et al. 1980). The Southern Blue Ridge had the highest median silica (9.0 mg L$^{-1}$) and total aluminum (81.7 $\mu$g L$^{-1}$) concentrations of any subregion, even though calcium and sulfate were low. Median nitrate (3.1 $\mu$eq L$^{-1}$) and potassium (39.4 $\mu$eq L$^{-1}$) were higher than in all other subregions. Such high constituent concentrations are typical of Southern Blue Ridge reservoirs (Placke 1983).

### *6.3.2 Florida (3B)*

Florida contained the largest number of acidic or low pH lakes of any subregion (22% or 463 lakes with ANC $\leq 0$ $\mu$eq L$^{-1}$; 12% or 259 lakes with pH $\leq 5.0$). Previous limnological studies have indicated that many lakes in Florida could generally be classified as acidic, softwater systems (Shannon and Brezonik 1972; Baker et al. 1981; Canfield 1981). Acidic lakes had somewhat higher extractable aluminum concentrations than the subregion as a whole, but very few Florida lakes had high concentrations of extractable aluminum. This is consistent with the findings of Hendry and Brezonik (1984), who noted acidic lakes in Florida do not currently have biologically meaningful aluminum concentrations. An estimated four percent of the clearwater lakes had extractable aluminum $\geq 100$ $\mu$g L$^{-1}$. This may be because aluminum concentrations are low in the sandy soils of Florida where many of the acidic lakes are located (Brezonik et al. 1983). However, aluminum in the sediments of Florida lakes may become available for release to overlying waters as pH of the water declines (Baker, L. 1984).

Seepage lakes were the most common type (66%) in Florida, followed by drainage lakes (22%) and closed lakes (13%). Florida lakes were generally medium-sized and shallow, and with small watersheds. Seepage lakes in Florida had the smallest lake and watershed areas but were deep. They were generally lower in ANC, pH, color, sulfate and calcium than drainage lakes. Sodium and chloride concentrations were high in Florida lakes; silica concentrations were exceptionally low (M = 0.3 mg $L^{-1}$). The order of cations and anions (Section 5.2.5.2, Table 5-5) was similar to that in Subregion 1D. At the $Q_1$ value, $Na^+$ and $Cl^-$ were dominant.

The highest variability observed for pH, sulfate and DOC occurred within Subregion 3B (Table 6-1). Based on the sample data, there appear to be at least five areas within the subregion containing lakes with distinct water chemistry characteristics. These are Southeast Georgia or the Okefenokee area, the Highland area of the Florida Panhandle, the Northcentral Peninsula of Florida, the Gulf Coast of Florida, and the Southcentral Peninsula of Florida. Selected subpopulation estimates were computed for these areas and will be discussed in this section. The boundaries of these areas are shown in Figure 6-1.

In Florida, 40 percent of the lakes had sulfate concentrations $\geq$150 $\mu$eq $L^{-1}$. In the Panhandle, 75 percent of the lakes (195) were estimated to have ANC $\leq$0 $\mu$eq $L^{-1}$ while in the Northcentral Peninsula only 21.7 percent of the lakes (209) had ANC $\leq$0 $\mu$eq $L^{-1}$. In the Panhandle, only 15.2 percent of the lake population had $SO_4^{-2}$ $\geq$50 $\mu$eq $L^{-1}$ while in the Northcentral Peninsula 91.9 percent had $SO_4^{-2}$ $\geq$50 $\mu$eq $L^{-1}$ and 60.7 percent had $SO_4^{-2}$ $\geq$150 $\mu$eq $L^{-1}$.

The majority of lakes in Subregion 3B were darkwater (56%). Unlike the reservoirs of the Southern Blue Ridge, color and DOC levels were related (for example, all darkwater lakes had DOC $\geq$6 mg $L^{-1}$). DOC was generally high in Florida lakes (69% had DOC $\geq$6 mg $L^{-1}$). Clearwater lakes in Florida were deeper, and had lower ANC and pH values, and calcium concentrations than did darkwater lakes. Canfield et al. (1984) found that color increased from north to south and inland from the coast. The subpopulation of lakes in the Okefenokee area (Figure 6-1) of 3B were highly colored and contained no lakes with DOC $\leq$6 mg $L^{-1}$. In the Panhandle, 65 percent of the lakes had DOC $\geq$6 mg $L^{-1}$ and the Northcentral Peninsula had 31 percent.

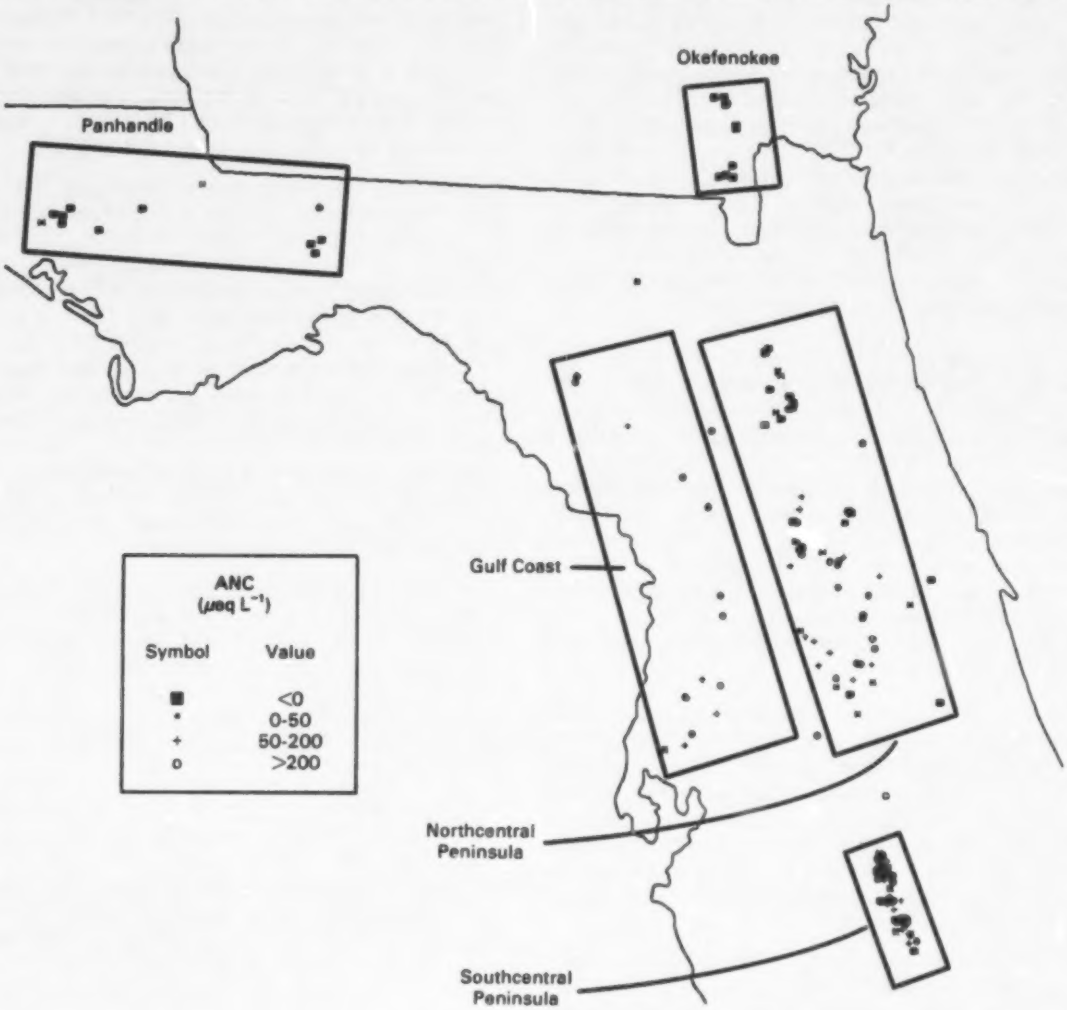
The Okefenokee and the Florida Panhandle subpopulations both had lakes with small surface areas (M = 6.1 and 10.2 ha, respectively), low pH (M = 4.1 and 4.9, respectively), low calcium (M = 17.9 and 18.4 $\mu$eq $L^{-1}$, respectively) low sulfate (M = 4.7 and 31.9 $\mu$eq $L^{-1}$, respectively) and mostly negative ANC values (M = -127.2 and -23.7 $\mu$eq $L^{-1}$, respectively). The Florida Panhandle lakes had low color (M = 14.7 PCU) and low DOC (M = 3.9 mg $L^{-1}$) and silica concentrations (M = 0.07 $\mu$eq $L^{-1}$), whereas the Okefenokee lakes were very shallow (M = 0.6 m), highly colored systems (M = 190 PCU) with high DOC (M = 35.7 mg $L^{-1}$) and very low sulfate concentrations (M = 4.7 $\mu$eq $L^{-1}$).

The lakes in the Northcentral Peninsula were relatively deep (M = 3.6 m), with circumneutral pH (M = 6.4), moderate color (M = 42.4 PCU), moderate ANC (M = 80.7 $\mu$eq $L^{-1}$), and DOC concentrations (M = 9.0 mg $L^{-1}$), high calcium (M = 225.1 $\mu$eq $L^{-1}$), high sulfate concentrations (M = 191.4 $\mu$eq $L^{-1}$), and very low silica concentrations (M = 0.37 $\mu$eq $L^{-1}$). The concentrations of sodium and sulfate in lakes that intercept deep groundwater flow are likely related to karst aquifers (Heath and Conover 1981). However, the influence of atmospheric contributions to regional aquatic chemistry has been proposed for Northcentral Peninsula seepage lakes that are not associated with karst groundwater inputs (Hendry and Brezonik 1984).

The lakes of the Southcentral Peninsula had higher sulfate (M = 454.9 $\mu$eq $L^{-1}$) and calcium concentratons (M = 308.2 $\mu$eq $L^{-1}$) and lower concentrations of DOC (M = 3.8 mg $L^{-1}$) than those in the Northcentral Peninsula. Canfield (1983) and Canfield et al. (1984) also found the greatest variability of pH and ANC in central Florida because of diverse geology and physiography.

Results of the current study show lakes along the Gulf Coast of Florida had high pH (M = 6.9) and high ANC (M = 414.2 $\mu$eq $L^{-1}$) and calcium (M = 463.2 $\mu$eq $L^{-1}$) concentrations. Sulfate and DOC concentrations were intermediate (M = 54.1 $\mu$eq $L^{-1}$ and 9.8 mg $L^{-1}$, respectively) with respect to all lakes in the Florida subregion.

Figure 6-1. Classes of ANC ($\mu eq\ L^{-1}$) in five selected subpopulations of lakes within Florida (3B), Eastern Lake Survey -Phase I.


Okefenokee
Panhandle
Gulf Coast
Northcentral Peninsula
Southcentral Peninsula
ANC ($\mu eq\ L^{-1}$)
Symbol
Value
■ <0
• 0-50
+ 50-200
o >200

# *Section 7*
# *Summary Observations*[8]

## 7.1 Objectives

The primary objectives of the Eastern Lake Survey were to:

1. determine the percentage (by number and area) and location of lakes in potentially sensitive regions of the U.S. that are acidic;
2. determine the percentage (by number and area) and location of lakes in potentially sensitive regions of the U.S. that have low acid neutralizing capacity; and
3. provide the data base for selecting regionally characteristic lakes for further study in Phases II (temporal variability and biological resources) and III (long-term monitoring) of the project.

The summary observations presented in Sections 7.2 and 7.3 address the first two objectives. The remaining summary observations address the third objective of the Survey. These observations lead to hypotheses that can be tested in subsequent phases of the National Surface Water Survey and/or the Aquatic Effects Research Program.

## 7.2 Extent and Location of Acidic and Low pH Lakes

The subregions in the Eastern U.S. that contain the largest proportion of acidic (ANC $\leq 0$ $\mu$eq $L^{-1}$) and low pH ($\leq 5.0$) lakes are the Adirondacks (1A), the Upper Peninsula of Michigan (2B) and Florida (3B).

### *7.2.1 Acidic Lakes*

- Within the Northeast (Region 1), the Adirondacks (1A) had the largest estimated number (138) and percentage (11%) of lakes with ANC $\leq 0$ $\mu$eq $L^{-1}$, followed by Southern New England (1D; 5%), and the Poconos/Catskills (1B; 5%) (Section 4.5.1.2). Maine (1E) had the lowest percentage of acidic lakes (<1%). Most acidic lakes in the Adirondacks (1A) occurred in the western portion of the subregion (Section 6.1.1).
- In the Upper Midwest (Region 2), 10 percent of the lakes in the Upper Peninsula of Michigan (2B) had ANC $\leq 0$ $\mu$eq $L^{-1}$, and three percent in Northcentral Wisconsin (2C) were acidic (Section 4.5.1.3). In Northeastern Minnesota (2A) and the Upper Great Lakes Area (2D) no acidic lakes were sampled.
- In the Southeast (Region 3), no acidic lakes were sampled in the Southern Blue Ridge (3A) (Section 4.5.1.4). In contrast, an estimated 22 percent of the lakes in Florida (3B) had ANC $\leq 0$ $\mu$eq $L^{-1}$.
- Acidic lakes in the Northeast had higher concentrations of sulfate, calcium, and extractable aluminum than did acidic lakes in the Upper Midwest and Southeast (Section 5.4).

### *7.2.2 Low pH Lakes*

The estimated number of lakes and lake area with low pH (pH $\leq 5.0$) also varied substantially among and within regions.

- Within the Northeast, the Adirondacks (1A) had the largest estimated number (128) and percentage (10%) of lakes with pH $\leq 5.0$. Subregion 1D (Southern New England) contained the second highest estimated number (66) and percentage (5%) and the largest area (2295 ha, 6%) of low pH lakes (Section 4.5.2.2). Maine (1E) had the fewest lakes (8, <1%) and least area (95 ha) with pH $\leq 5.0$.
- In the Upper Midwest, no lakes with pH $\leq 5.0$ were observed in Northeastern Minnesota (2A) or the Upper Great Lakes Area (2D) (Section 4.5.2.3). The Upper Peninsula of Michigan (2B) was estimated to contain 99 lakes with pH $\leq 5.0$, representing nearly the same proportion as in the Adirondacks (9% and 10%, respectively).
- In the Southeast, no lakes with pH $\leq 5.0$ were sampled in the Southern Blue Ridge (3A) (Section 4.5.2.4). Florida (3B) had the highest estimated number and percentage of lakes (259, 12%) and the largest estimated lake area with pH $\leq 5.0$.

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[8] The numbers and percentages of lakes cited here are population estimates.

## 7.3 Extent and Location of Low ANC Lakes

As observed with the estimates of low pH lakes, the estimated number of lakes with low ANC varied among and within regions.

- Within the Northeast, the Adirondacks (1A) contained the highest percentages of lakes with ANC ≤50 μeq $L^{-1}$ and ≤200 μeq $L^{-1}$ (36% and 70%, respectively) (Section 4.5.1.2). Central New England (1C) and Maine (1E) contained the next highest percentages of lakes among all eleven subregions with ANC ≤200 μeq $L^{-1}$ (68% and 67%, respectively).

- Northcentral Wisconsin (2C) contained the highest percentage (41%) of lakes with ANC ≤50 μeq $L^{-1}$ among all eleven subregions (Section 4.5.1.3). Northeastern Minnesota (2A) and Northcentral Wisconsin (2C) contained the highest percentage of lakes in the Upper Midwest with ANC ≤200 μeq $L^{-1}$ (57%). Although the Upper Great Lakes Area (2D) contained the lowest percentages in the Upper Midwest of lakes with ANC ≤200 μeq $L^{-1}$, it contained the largest number of lakes among all eleven subregions in this category (1411).

- The Southern Blue Ridge (3A) contained the lowest percentage (1%) and number (4) of lakes with ANC ≤50 μeq $L^{-1}$ and the lowest number of lakes with ANC ≤200 μeq $L^{-1}$ among all eleven subregions (Section 4.5.1.4). Florida (3B) contained the highest number of lakes among all subregions with ANC ≤50 μeq $L^{-1}$, and the second highest number of lakes with ANC ≤200 μeq $L^{-1}$.

## 7.4 Chemical Characterization

### *7.4.1 Sulfate*

Sulfate concentrations in lakes were greatest in Florida and the southern portions of the Northeast. No linear relationship between lakewater sulfate and pH or ANC was evident in any region. High concentrations of sulfate were found at low and high pH values.

- Sulfate concentrations were relatively high in the Northeast (median concentration (M) = 115.4 μeq $L^{-1}$) (Section 4.6.1). Within the Northeast, sulfate concentrations were highest in the Poconos/Catskills (1B; M = 159.3 μeq $L^{-1}$) and Southern New England (1D; M = 141.1 μeq $L^{-1}$). The lowest sulfate values were observed in Maine (1E; M = 74.6 μeq $L^{-1}$).

- The median sulfate concentration in the Upper Midwest was half that of the Northeast (Section 4.6.1). Median sulfate concentrations also varied among subregions within the Upper Midwest, ranging from 50.1 μeq $L^{-1}$ in the Upper Great Lakes Area (2D) to 77.7 μeq $L^{-1}$ in the Upper Peninsula of Michigan (2B).

- In the Southeast, the Southern Blue Ridge (3A) contained few lakes with high sulfate (22 or 8% with $SO_4^{-2}$ ≥150 μeq $L^{-1}$) (Section 4.6.1). This subregion also had the lowest median sulfate concentration, 31.8 μeq $L^{-1}$. Florida (3B) contained the largest number of lakes with high sulfate concentrations (846 or 40% with $SO_4^{-2}$ ≥150 μeq $L^{-1}$). Subregion 3B also had the most variable sulfate concentrations of any subregion ($Q_d$ = 244 μeq $L^{-1}$).

### *7.4.2 Calcium*

Calcium concentrations were lowest in the Upper Midwest and Florida lakes.

- Within the Northeast, Southern New England (1D) had the highest percentage and number of lakes with calcium concentrations ≤50 μeq $L^{-1}$ (10%; 133) (Section 4.6.2). The Adirondacks (1A) contained the second highest percentage and number (8%; 108) of low calcium lakes (≤50 μeq $L^{-1}$).

- Northcentral Wisconsin (1C) contained the highest percentage (22%) and second highest number (34) of low calcium lakes among all subregions (Section 4.6.2). The Upper Peninsula of Michigan (2B) contained the second highest percentage (16%) of low calcium lakes and the Upper Great Lakes Area (2D) contained the second highest number (256) of low calcium lakes in the Upper Midwest.

- In the Southeast, 12 percent of the lakes in the Southern Blue Ridge (3A) had low concentrations of calcium, whereas in Florida (3B), 19 percent of the lakes were in this group (Section 4.6.2). Florida (3B) contained the highest number (402) of low calcium lakes among all subregions.

### *7.4.3 Extractable Aluminum*

Extractable aluminum concentrations were higher in lakes with lower pH values, and higher in the Northeast than in other regions.

- The largest estimated number of clearwater lakes having extractable aluminum concentrations ≥150 μg $L^{-1}$ occurred in the Adirondacks (1A; 82 lakes or 10%) (Section 4.6.3). Few lakes in the Poconos/Catskills (1B; 3 lakes or <1%) and Southern New England (1D; 7 lakes or 1%) had extractable aluminum ≥150 μg $L^{-1}$. No clearwater lakes sampled in Maine (1E) had extractable aluminum concentrations ≥50 μg $L^{-1}$.

- Extractable aluminum concentrations in clearwater lakes were lower in the Upper Midwest ($Q_4 = 8.5$ $\mu g$ $L^{-1}$) than in the Northeast ($Q_4 = 11.6$ $\mu g$ $L^{-1}$) (Section 4.6.3). Extractable aluminum was lowest in clearwater lakes in Northeastern Minnesota (2A; $Q_4 = 3.0$ $\mu g$ $L^{-1}$), and highest in clearwater lakes in the Upper Peninsula of Michigan (2B; $Q_4 = 11.9$ $\mu g$ $L^{-1}$).
- Extractable aluminum concentrations in clearwater lakes were low in the Southern Blue Ridge (3A; $Q_4 = 2.5$ $\mu g$ $L^{-1}$) (Section 4.6.3). In Florida (3B), clearwater lakes had lower extractable aluminum concentrations ($Q_4 = 18.6$ $\mu g$ $L^{-1}$) than did clearwater lakes in the Adirondack subregion (1A; $Q_4 = 29.4$ $\mu g$ $L^{-1}$) (Section 5.4).
- In each region extractable aluminum concentrations were higher at lower pH values (Section 5.2.3.2). The Northeast had the greatest increase in extractable aluminum with decreasing pH and Florida the least increase at low pH values.

### 7.4.4 Dissolved Organic Carbon

Dissolved organic carbon (DOC) concentrations did not correlate with the distribution of acidic or low ANC lakes.

- In the Northeast, as in other regions, 80 percent of acidic lakes contained concentrations of DOC $<5$ mg $L^{-1}$ (Section 5.4). A positive relationship existed between pH and DOC. Those lakes with highest DOC concentrations were drainage lakes with short hydraulic residence times and nigh ANC (Section 5.3.2).
- In the Upper Midwest, most acidic lakes, especially those in the Upper Peninsula of Michigan (2B) and Northcentral Wisconsin (2C), were clearwater, low DOC, seepage lakes (Section 6.2). Lakes in Northeastern Minnestoa (2A) had the highest concentrations of DOC in the Upper Midwest and no acidic lakes were sampled in this subregion (Sections 4.5.1 and 4.6.4).
- In the Southeast, only the lakes within the Okefenokee Swamp exhibited a strong association between low pH and high DOC. No apparent relationship between pH and DOC was evident in Florida (3B) lakes (Section 6.3.2).

### 7.4.5 Major Cations and Anions

The anions were most useful in characterizing differences in the relative importance of major ions among regions and subregions.

- In the Northeast, sulfate was the predominant anion at the 20th percentile in three of the subregions (Adirondacks, 1A; Poconos/Catskills, 1B; and Central New England, 1C) (Section 5.2.5.2). Sulfate was also the dominant anion at the median value in the Adirondacks (1A).
- In Maine (1E), bicarbonate ion concentrations exceeded sulfate at both the 20th percentile and the median (Section 5.2.5.2).
- Chloride was the dominant anion in Southern New England (1D) at both the 20th percentile and median values estimated for the population (Section 5.2.5.2).
- Bicarbonate was the dominant anion at the 20th percentile and median values in the Upper Midwest, with the exception of the Upper Peninsula of Michigan (2B) and Northcentral Wisconsin (2C), where sulfate was dominant at the 20th percentile (Section 5.2.5.2).
- The ionic composition of lakes in Florida (3B) was similar to that of lakes in Southern New England (1D) in that sodium was the dominant cation and chloride the dominant anion at the 20th percentile (Section 5.2.5.2). Total ionic concentration of many Florida lakes was high.
- Organic anions, as indicated by anion deficit, were not the dominant anions in any subregion at either the 20th or 50th percentiles (Section 5.2.6.2). Concentrations of organic anions were especially low in the Northeast.

## 7.5 Future Studies

The results of the Survey presented in this report are largely descriptive. However, the statistical design of the Survey makes it possible to test acidification hypotheses and to examine the results with respect to a population of lakes. Future aspects of the National Lake Survey combined with other data bases can address, in part, the following questions.

- Sulfate concentrations in lakes across the Northeast and the Upper Midwest show an apparently strong relationship with the general patterns of sulfate deposition as measured by the National Trends Network. *What is the nature of the relationship between lake chemistry and atmospheric deposition of sulfate?*
- The majority of acidic lakes in all three regions contained relatively low concentrations of organic acids. *How important are the contributions of organic acids in explaining the occurrence of acidic lakes?*
- Some portions of the coastal areas of the Northeast contained moderate numbers of acidic lakes. *To what degree can the acidity of these coastal lakes be attributed to a neutral salt effect from sea spray deposition?*

- **The estimated hydraulic residence times for clearwater lakes were approximately 3 times greater than for darkwater lakes. Residence time was inversely related to DOC.** ***Does an apparent difference in hydrology between clearwater, acidic lakes and darkwater, higher ANC lakes indicate that acidic lakes generally are not derived from darkwater lakes?***
- **Florida (3B) contained the largest proportion of acidic lakes and their chemistry differed considerably in many respects from lakes in the Northeast, Upper Midwest and Southern Blue Ridge (3A).** ***To what degree are the acidic lakes in Florida affected by acidic deposition, and are other factors more important in explaining the occurrence of acidic lakes in Florida?***

## Section 8
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# Section 9
# Glossary

## 9.1 Abbreviations

$\hat{A}$—estimated total lake area in a target population
$\Sigma A$—area in a population of target lakes
$\hat{A}_c$—estimated lake area below $X_c$
$A_{cu}$—95% upper confidence limit on $A_c$
ANC—acid neutralizing capacity
cm—centimeter
DIC—dissolved inorganic carbon
DOC—dissolved organic carbon
DQO—data quality objective
ELS-I—Eastern Lake Survey - Phase I
EPA—Environmental Protection Agency
ERL-C—Environmental Research Laboratory - Corvallis
EMSL-LV—Environmental Monitoring Systems Laboratory - Las Vegas
F(x)—cumulative frequency distribution for lakes
G(x)—cumulative areal distribution for lakes
$g_c$—reference proportion (lake area)
ID—identification number
m—meter
M—median value of F(x)
MIBK—methyl isobutyl ketone
mg $L^{-1}$—milligrams per liter
$\hat{N}$—estimated number of lakes in a target population
$N^*$—number of lakes in frame population
$n^*$—number of lakes selected in probability sample
$n^{**}$—number of lakes visited
$n^{***}$—number of target lakes sampled
$n'$—effective sample size
$n_o$—number of lakes not visited
$n_{na}$—number of non-target lakes in the sample determined after visiting the lake
$n_{nb}$—number of non-target lakes in the sample determined from maps before visitation
$\hat{N}_c$—estimated number of lakes below $X_c$
$\hat{N}_{cu}$—95% upper confidence limit on $N_c$
NAPAP—National Acid Precipitation Assessment Program
NBS—National Bureau of Standards
NLS—National Lake Survey
NSWS—National Surface Water Survey
NTU—nephelometric turbidity unit
ORNL—Oak Ridge National Laboratory
$p_c$—reference proportion (number of lakes)
PCU—platinum cobalt units
q—proportion of lakes visited
$Q_1$—first quintile of F(x) or G(x)
$Q_2$—second quintile of F(x) or G(x)
$Q_3$—third quintile of F(x) or G(x)
$Q_4$—fourth quintile of F(x) or G(x)
QA—quality assurance
QC—quality control
QCCS—quality control check samples
RDL—required detection limit
%RSD—percent relative standard deviation
SAS—Statistical Analysis System
SD—standard deviation
SDL—system decision limit
SE—standard error
$\mu$eq $L^{-1}$—microequivalents per liter
$\mu$g $L^{-1}$—micrograms per liter
$\mu$m—micrometers
$\mu$S—microsiemens
USGS—United States Geological Survey
V—variance
W—weight or expansion factor
$X_c$—reference value of the variable X

## 9.2 Definitions

ACID NEUTRALIZING CAPACITY (ANC) - the total acid-combining capacity of a water sample determined by titration with a strong acid. ANC includes ALKALINITY (carbonate species) as well as other basic species (e.g., borates, dissociated ORGANIC ACIDS, alumino-hydroxy complexes).

ACIDIC DEPOSITION - rain, snow, or dry fallout containing high concentrations of sulfuric and/or nitric acids, usually produced by atmospheric transformation of the by-products of fossil fuel combustion (power plants, smelters, autos, etc.); precipitation with a pH <5.0 is generally considered to be unnaturally acidic.

ACIDIC LAKE - for this report, a lake with ACID NEUTRALIZING CAPACITY (ANC) $\leq 0$ µeq $L^{-1}$.

ACIDIFICATION - loss of acid neutralizing capacity, either temporary or permanent.

AIR-EQUILIBRATED - a sample aliquot that has been brought to equilibrium with standard air (300 ppm $CO_2$) prior to analysis; used with some pH and DIC measurements.

ALIQUOT - portion of a sample prepared for the analysis of particular constituents, sent in a separate container to the ANALYTICAL LABORATORY.

ALKALINITY - the titratable base of a sample containing hydroxide, carbonate, and bicarbonate ions, i.e. the equivalents of acid required to neutralize the basic carbonate components.

ALKALINITY MAP CLASS - a geographic area defined by the expected ALKALINITY of SURFACE WATERS (does not necessarily reflect measured alkalinity); used as a STRATIFICATION FACTOR in ELS-I design.

ALLOCTHONOUS - from a source outside the system under consideration.

AMONG-BATCH PRECISION - the estimate of precision that includes effects of different laboratories and day-to-day difference within a single laboratory.

ANALYTICAL LABORATORY - in this report, a laboratory under contract with the EPA to analyze ELS-I water samples shipped from the FIELD LABORATORIES.

ANION - a negatively charged ion.

ANION-CATION BALANCE - in an electrically neutral solution, such as water, the total charge of positive ions (CATIONS) equals the total charge of negative ions (ANIONS); this calculation is used as a quality assurance check.

ANION DEFICIT - the amount in µeq $L^{-1}$ of measured ANIONS less than measured CATIONS.

ANTHROPOGENIC - from a human source.

AUDIT - an onsite evaluation of a laboratory to verify that standardized protocols are being followed.

AUDIT SAMPLE - a standardized water sample submitted to laboratories to check overall performance in sample analysis. Natural audit samples were lake water; synthetic audit samples were prepared by diluting concentrates of known composition. See FIELD AUDIT SAMPLE and LABORATORY AUDIT SAMPLE.

BASE CATION - a non-protolytic cation that does not affect ANC; usually $Ca^{+2}$ or $Mg^{+2}$.

BATCH - a group of samples processed and analyzed together. A field batch of samples is defined as all samples (including quality assurance samples) processed at one FIELD LABORATORY in one day. A laboratory batch is defined as all samples processed and analyzed at one ANALYTICAL LABORATORY, associated with one set of laboratory QUALITY CONTROL samples.

BIAS - the expected value of the difference between a measurement and a true value being measured.

BINOMIAL FORMULATION - refers to the binomial probability distribution, which describes the outcome of a sequence of identical and independent random trials, each of which can result in one of two outcomes (coin flipping is a common example).

BLANK - a sample of ASTM Type I reagent grade water analyzed as a QUALITY ASSURANCE/ QUALITY CONTROL sample in the ELS-I. See FIELD BANK SAMPLE and LABORATORY BLANK SAMPLE.

BUFFERING CAPACITY - the property of a solution that permits the relative concentrations of hydrogen and hydroxyl ions to be maintained by neutralizing, within limits, added acids or bases.

CARBONATE SYSTEM - a lake in which the major part of the ANC is composed of carbonates; organic or other weak anions are less than 10% of total ANION charge.

CATION - a positively charged ion.

CATION EXCHANGE - a process occurring in soil in which acid cations (usually hydrogen ions) are adsorbed and BASE CATIONS are released.

CHELATOR - a class of compounds, organic and inorganic, that can bind metal ions and change their biological availability.

CHROMOPHORE - a chemical group that gives rise to color in a molecule.

CLEARWATER LAKE - for this report, a lake having true color less than or equal to 30 PLATINUM COBALT UNITS (PCU).

CLOSED LAKE - a lake with a surface water inlet but no surface water outlet.

CLOSED SYSTEM - method of measurement in which a water sample is collected and analyzed for pH and DIC without exposure to the atmosphere.

CLUSTER ANALYSIS - a multivariate classification technique for identifying similar (or dissimilar) groups of observations.

COLLOIDAL PARTICLES - particles of suspended matter that are too small to settle from solution and often too small to be removed by filtration.

CONDUCTANCE - a measure of the electrical conductance (the reciprocal of the electrical resistance) or total ionic strength of a water sample.

CONFIDENCE BOUND or LIMIT (95%) - a value that, in association with a statistic, has a 95% chance of being above (or below) the true value of the population parameter of interest.

CUMULATIVE FREQUENCY DISTRIBUTION - a curve such that at any value x, the F(x) represents the estimated proportion of lakes in the population having a value for that variable that is less than or equal to x.

DARKWATER LAKE - for this report, a lake with true color greater than 30 PLATINUM COBALT UNITS (PCU).

DATA BASE - all computerized results of the Survey, which includes DATA SETS 1-4 as well as back-up and historical data sets.

DATA FILE - a subset of information, often in tabular form (e.g. the lake location file contains information on lake identifiction and location only).

DATA QUALIFIER - see FLAG and TAG.

DATA QUALITY OBJECTIVES (DQOs) - precision limits desired by data users, established prior to the beginning of the sampling effort.

DATA SET 1 - set of files containing RAW data.

DATA SET 2 - set of files containing VERIFIED data.

DATA SET 3 - set of files containing VALIDATED data.

DATA SET 4 - set of files containing final, enhanced data; missing values or errors in the VALIDATED data set were replaced by substitution values, duplicate values were averaged, and negative measurements (except ANC) were set equal to zero.

DEGASSING - the loss of dissolved $CO_2$ from a water sample, which can result in changes in pH and DIC between the time of collection and the time of analysis.

DISSOLVED INORGANIC CARBON (DIC) - a measure of the dissolved carbon dioxide, carbonic acid, and carbonate and bicarbonate anions which comprise the major part of ANC in a lake.

DISSOLVED ORGANIC CARBON (DOC) - the organic fraction of carbon in a water sample that is dissolved or unfilterable (for this report, 0.45 μm pore size).

DRAINAGE BASIN - see WATERSHED.

DRAINAGE LAKE - a lake with surface water outlet(s) or with both inlets and outlets.

EFFECTIVE SAMPLE SIZE (n') - within each STRATUM, the total sample size modified because of incomplete visitation.

EMPIRICAL DISTRIBUTION - observed distribution of results from the Survey.

EPILIMNION - the surface layer of warmer water above the thermocline in a STRATIFIED LAKE.

EQUIVALENT - unit of ionic charge; the quantity of a substance that either gains or loses 1 mole of protons or electrons.

EXPANSION FACTOR - see WEIGHT.

EXTRACTABLE ALUMINUM - operationally defined aluminum fraction that is extracted by the procedure used in the ELS-I; this measurement is intended to provide an indication of the concentration of aluminum that may be available in a toxic form.

FALL CIRCULATION - see TURNOVER.

FIELD AUDIT SAMPLE - a standardized water sample submitted to FIELD LABORATORIES to check overall performance in sample analysis by both FIELD and ANALYTICAL LABORATORIES. Natural field audit samples were lake water; synthetic field audit samples were prepared by diluting concentrates of known composition.

FIELD BLANK SAMPLE - a sample of ASTM Type I reagent grade water prepared at the lake site by each field crew each day that sampling occurred; these samples were analyzed by both FIELD and ANALYTICAL LABORATORIES.

FIELD DUPLICATE SAMPLE - a second sample of lake water collected by the same crew at the same lake site immediately after the ROU-

TINE SAMPLE in accordance with standardized protocols.

FIELD LABORATORY - mobile laboratory located at each FIELD STATION in which sample processing and measurement of selected parameters were performed.

FIELD STATION - a location providing support for helicopters, sampling personnel, and FIELD LABORATORIES during field sampling operations.

FLAG - qualifier of a data value assigned during the VERIFICATION and VALIDATION procedures.

FORM 1 - the field data form completed by field sampling personnel.

FORM 2 - the field BATCH form completed by field laboratory personnel.

FORM 3 - sample tracking form completed in the field laboratory and used by the sample management office.

FRAME - a structural representation of a population providing a sampling capability.

FRAME POPULATION - within each STRATUM, the ordered list of lakes depicted on 1:250,000-scale U.S. Geological Survey maps.

GROUNDWATER - water in the part of the ground that is completely saturated.

HARDWATER - water with high concentrations of calcium and magnesium salts.

HECTARE - 2.47 acres or ten thousand square meters.

HIGH DOC LAKE - for this report, a lake with DOC concentration greater than or equal to 6 mg $L^{-1}$.

HIGH SULFATE LAKE - for this report, a lake with sulfate concentration greater than or equal to 150 $\mu$eq $L^{-1}$.

HYPOLIMNION - the bottom layer of cold water below the THERMOCLINE in a STRATIFIED LAKE.

IN SITU - referring to measurements made at the lake sampling site.

INDEX - in this report, one sample per lake, used to represent chemical conditions in that lake.

INTERQUARTILE RANGE - the difference between the upper and lower quartile values in a population frequency distribution (see QUARTILE).

INSTRUMENT DETECTION LIMIT - for each chemical parameter, a value calculated from LABORATORY BLANK SAMPLES that indicates the minimum concentration reliably detectable by the instrument(s) used.

INTRA LABORATORY PRECISION GOAL - a precision goal based on the DATA QUALITY OBJECTIVES for the analysis of laboratory duplicates within a single laboratory.

IONIC STRENGTH - a measure of the interionic effect resulting from the electrical attraction and repulsion between various ions. In very dilute solutions, ions behave independently of each other and the ionic strength can be calculated from the measured concentrations of anions and cations present in the solution.

ISOTHERMAL - defined as a temperature difference in a lake of less than 4°C between the reading at 1.5 m below the surface and at 1.5 m above lake bottom (synonymous with unstratified or mixed).

LABORATORY AUDIT SAMPLE - a standardized water sample submitted blind to ANALYTICAL LABORATORIES to check overall performance in sample analysis. All laboratory audit samples were synthetic, prepared by diluting concentrates of known chemical composition.

LABORATORY BLANK SAMPLE - a sample of ASTM Type I reagent grade water prepared and analyzed by ANALYTICAL LABORATORIES

LABORATORY DUPLICATE SAMPLE - an aliquot that is split and analyzed twice for a given suite of variables at the ANALYTICAL LABORATORIES.

LAKE ID - a unique, seven-character identification code given to each lake in the Survey designating the REGION, SUBREGION, and ALKALINITY MAP CLASS to which the lake belongs; e.g., lake ID IA2-101 designates the 101st lake in alkalinity map class 2 of Subregion A in Region 1.

LAKE TYPE - a classification of lakes based on the presence or absence of inlets, outlets, and dams as represented on large-scale maps.

LARGE-SCALE MAPS - 1:24,000-, 1:25,000-, or 1:62,500-scale U.S. Geological Survey topographic maps.

LONG-TERM ACIDIFICATION - permanent loss of ANC from a lake.

LONG-TERM MONITORING PROGRAM - an EPA sponsored program that monitors the chemistry of selected lakes and streams at least three times a year.

LORAN-C GUIDANCE SYSTEM - a navigational system based upon the time-delay of received radio signals. The system provides latitude and longitude at any point on the earth's surface.

LOW ANC LAKE - for this report, a lake with ANC less than or equal to 50 $\mu$eq L$^{-1}$.

LOW CALCIUM LAKE - for this report, a lake with calcium concentration less than or equal to 50 $\mu$eq L$^{-1}$.

LOW DOC LAKE - for this report, a lake with DOC concentration less than or equal to 2 mg L$^{-1}$.

LOW pH LAKE - for this report, a lake with pH less than or equal to 5.0.

MACROPHYTE - macroscopic forms of aquatic vegetation, including macroalgae, aquatic mosses and ferns, as well as true angiosperms.

MAP POPULATION - see FRAME POPULATION.

MATRIX - the physical and chemical makeup of a sample being analyzed.

MEDIAN - (M) the value of x such that F(x) or G(x) = 0.5; half the lakes in the population are estimated to have $x \leq M_F$ and half the lake area is estimated to have a value of $x \leq M_G$.

MEROMICTIC LAKE - a lake that does not undergo complete mixing or turnover due to chemically-induced, as opposed to thermally-induced, stratification.

MIXING - see TURNOVER.

MODERATE ANC LAKE - for this report, a lake with ANC less than or equal to 200 $\mu$eq L$^{-1}$ and greater than 50 $\mu$eq L$^{-1}$.

MODERATE pH LAKE - for this report, a lake with pH less than or equal to 6.0 and greater than 5.0.

NONSTRATIFIED - see ISOTHERMAL.

NON-TARGET LAKE - a lake that either was not the focus of the ELS-I objectives or could not be sampled within the constraints of the Survey.

NOT VISITED LAKE - a REGULAR LAKE scheduled for sampling that was not visited or sampled during field activities; thus, its TARGET or NON-TARGET status is unknown.

OLIGOTROPHIC LAKE - a lake with low primary productivity.

ORDERING FACTORS - factors used to order lakes within a STRATUM prior to lake selection by SYSTEMATIC RANDOM SAMPLING; the factors used were elevation and lake type.

ORGANIC ACIDS - acids possessing a carboxyl (-COOH) group; includes fulvic and humic acids.

OUTLIERS - observations not typical of the population from which the sample is drawn.

OVERALL PRECISION - estimate of precision that includes the effects of sample collection, handling and analysis.

PERCENT RELATIVE STANDARD DEVIATION (% RSD) - coefficient of variation.

pH - the negative logarithm of the hydrogen ion concentration; waters with lower pH are more acidic; a difference of one pH unit indicates ten times more (or less) acidity.

PHYSIOGRAPHY - the elevation, slope, and shape of the landform, including its spatial relationships with other physical features.

PLATINUM COBALT UNIT (PCU) - measure of the color of a water sample defined by a potassium hexachloroplatinate and cobalt chloride standard color series.

POPULATION ESTIMATE - a statistical estimate that applies to a specific population of TARGET LAKES, not only to the sample.

PRIMARY VARIABLES - variables of foremost concern in the Survey (pH, ANC, extractable Al, SO$_4^{-2}$, Ca$^{+2}$, DOC).

PROBABILITY SAMPLE - a sample in which each unit (lake, in this case) has a known probability of being selected.

QUALITY ASSURANCE - those management steps taken to ensure that a study is adequately planned and implemented to provide data of the highest quality, and that adequate information is provided to determine the quality of the DATA BASE resulting from this study.

QUALITY CONTROL - those steps taken during sample collection and analysis to ensure that the data quality meets the minimum standards established by the QUALITY ASSURANCE plan.

QUALITY CONTROL CHECK SAMPLES (QCCS) - samples of known concentration used to verify continued calibration of instruments.

QUANTITATION LIMIT - for each chemical parameter, a value calculated from FIELD BLANK SAMPLES that represents the lowest concentration that can be measured with reasonable precision.

QUARTILE - any of the three values that divide the population of a frequency distribution into four equal classes, each representing 25 percent; used to measure range or variation.

QUINTILE - any of the four values ($Q_1$, $Q_2$, $Q_3$, $Q_4$) that divide the population of a frequency distribution into five equal classes, each representing 20 percent; used to provide additional values to compare among populations of lakes (see CUMULATIVE FREQUENCY DISTRIBUTION).

RAW DATA SET - the initial data set (DATA SET 1) that has received a cursory review to confirm that data are provided in proper format and are complete and legible.

REFERENCE VALUE ($X_c$) - a concentration of interest for a given chemical variable.

REGION - a major area of the conterminous United States where a substantial number of lakes with ALKALINITY less than 400 $\mu eq\ L^{-1}$ can be found.

REGULAR LAKE - in this study, a lake that is in the PROBABILITY SAMPLE of lakes selected from the FRAME POPULATION.

REMOTE BASE SITE - location serving as a base of operations for sampling crews working more than 100 miles from the FIELD LABORATORY; samples were flown to the field laboratory daily.

REQUIRED DETECTION LIMIT - for each chemical parameter, the INSTRUMENT DETECTION LIMIT required in the ANALYTICAL LABORATORY contract.

ROOT MEAN SQUARE - a summary statistic calculated as $(\Sigma S_{i/n}^2)^{1/2}$, where $S_{i/n}$ = the STANDARD DEVIATION.

ROUTINE SAMPLE - the first lake sample collected at a site in accordance with standardized protocols.

SAS - Statistical Analysis System, Inc. (Cary, NC). A statistical data file manipulation package that has data management, statistical, and graphical analysis abilities. The ELS-I data base was developed and analyzed primarily using SAS software, and is distributed in SAS format.

SECCHI DISK - a 20-cm-diameter, black and white disk used to measure water transparency.

SECONDARY VARIABLES - chemical variables measured during the Survey considered to be important in providing additional data in quantifying the chemical status of lakes, e.g., sodium, magnesium, potassium, nitrate, chloride and total aluminum.

SEEPAGE LAKE - a lake with no permanent surface water inlets or outlets.

SHALLOW LAKE - a lake from which a clean sample could not be obtained at 1.5 m below the surface but could be obtained at 0.5 m; these lakes were generally less than 3 m deep.

SMALL-SCALE MAP - 1:250,000-scale U.S. Geological Survey map.

SOFTWATER - water with low concentrations of calcium and magnesium salts.

SPECIAL INTEREST LAKE - in this Survey, a lake selected non-randomly, thus not part of the PROBABILITY SAMPLE; selection was based on quality and amount of data available or involvement in other research programs.

SPLIT SAMPLE - a subsample of a field BATCH sample that was sent to other laboratories for analysis.

STANDARD DEVIATION - the square root of the variance of a given statistic.

STRATIFICATION FACTORS - factors used to define STRATA prior to lake selection; the factors used in the ELS-I where REGION, SUBREGION and ALKALINITY MAP CLASS.

STRATIFIED DESIGN - a statistical design in which the population is divided into strata, and a sample selected from each STRATUM.

STRATIFIED LAKE - in this report, a lake with a temperature difference greater than 4°C between the water layers at 1.5 m below the surface and 1.5 m above the lake bottom. If the temperature difference is also greater than 4°C between the water layers at 1.5 m below the surface and 60% of site depth, then the lake is strongly stratified, if not, it is weakly stratified.

STRATUM - in this Survey, a subpopulation of lakes within an ALKALINITY MAP CLASS within a SUBREGION and within a REGION, as defined by the STRATIFIED DESIGN.

SUBPOPULATION - any defined subset of the TARGET POPULATION.

SUBREGIONS - areas within each REGION that are similar in water quality, physiography, vegetation, climate, and soil; used as a STRATIFICATION FACTOR in ELS-I design.

SURFACE WATER - streams and lakes.

SYNOPTIC - relating to or displaying conditions as they exist simultaneously over a broad area.

SYSTEM DECISION LIMIT - for each chemical parameter, a value calculated from FIELD BLANK data that reliably (with 95% confidence) indicates a concentration above background levels.

SYSTEMATIC ERROR - a consistent error introduced in the measuring process. Such error commonly results in biased estimations.

SYSTEMATIC RANDOM SAMPLING - a sampling technique in which the units in the population are ordered, a first sampling unit is randomly drawn from the first K units, and every kth unit afterward is included in the sample (K being equal to N divided by the sample size).

TAG - code on a data point that is added at the time of collection or analysis to qualify the data.

TARGET POPULATION - in this Survey, the lake population of interest that was sampled. This population was defined by the sampling protocol.

THERMOCLINE - the area of most rapid temperature change with depth in a STRATIFIED LAKE.

TITRATION DATA - individual data points from the modified Gran analysis of ANC.

TOPOGRAPHIC MAP - a map showing contours of surface elevation.

TRANSPARENCY - the clarity of unfiltered water.

TRAILER DUPLICATE - a sample that is split and analyzed twice in the FIELD LABORATORY.

TRUE COLOR - the color of water that has been filtered or centrifuged to remove particles that may impart an apparent color; true color ranges from clear blue to blackish-brown.

TURBIDITY - a measure of light scattering by suspended particles in an aqueous solution.

TURNOVER - a period of circulation in lakes when little or no differences in temperature are observed with depth.

VALIDATION - process by which data are evaluated for quality with reference to the intended data use; includes identification of OUTLIERS and evaluation of potential SYSTEMATIC ERROR.

VERIFICATION - process of ascertaining the quality of the data in accordance with the minimum standards established by the QUALITY ASSURANCE plan.

WATERSHED - the geographic area from which surface water drains into a particular lake.

WATERSHED DISTURBANCE - a disturbance of the natural environment in a watershed within 100 m of the shore as noted by field samplers. Disturbances were roads, houses, logging, mining and livestock.

WEAK ACID SYSTEM - a lake in which more than 10% of the anion charge results from organic acids or other weak acid anions.

WEIGHT - the inverse of a sample lake's inclusion probability; each sample lake represents this number of lakes in the population.

WITHIN-BATCH PRECISION - the estimate of precision expected in the analysis of samples in a BATCH by the same laboratory on any single day (in this report, overall within-batch precision includes the effects of sample collection, processing and analysis; analytical within-batch precision includes the effects of sample analysis within ANALYTICAL LABORATORIES).

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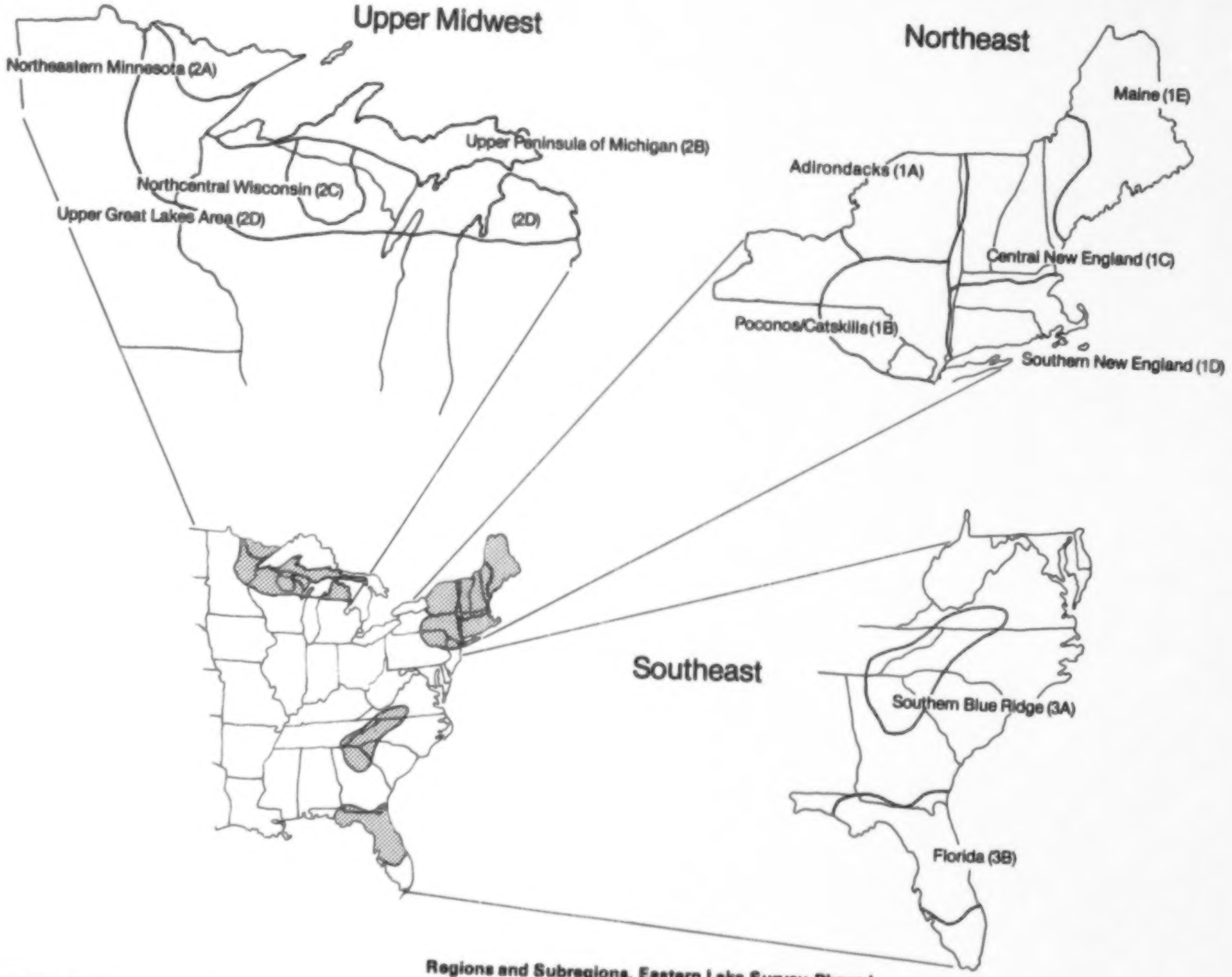
Upper Midwest
Northeastern Minnesota (2A)
Upper Peninsula of Michigan (2B)
Northcentral Wisconsin (2C)
Upper Great Lakes Area (2D)
(2D)
Northeast
Maine (1E)
Adirondacks (1A)
Central New England (1C)
Poconos/Catskills (1B)
Southern New England (1D)
Southeast
Southern Blue Ridge (3A)
Florida (3B)

Regions and Subregions, Eastern Lake Survey-Phase I